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FRACTURE MECHANICS ANALYSIS OF SINGLE AND DOUBLE ROWS OF FASTENER HOLES LOADED IN BEARING

AEROELASTIC AND STRUCTURES RESEARCH LABORATORY
DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139

APRIL 1976

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Prepared For
AIR FORCE FLIGHT DYNAMICS LABORATORY
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This report documents a finite-element analysis procedure for computation of Mode I and Mode II stress intensity factors at a cracked fastener hole in a single row or a double staggered row of fastener holes on a tension panel. The panel is loaded by cosine bearing pressure distributions applied to each fastener hole. Different bearing forces may be specified for each hole, and any hole may be designated as the damaged hole. The physical structure, finite-element model, program flow and options, input/

output conventions, execution times, and limitations are discussed. Results of some example analyses are presented.

FOREWORD

The developments documented in this report were carried out at the Aeroelastic and Structures Research Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, under Contract No. F33615-74-C-3063 (Project 1367, Task 136703) from the U.S. Air Force Flight Dynamics Laboratory. Mr. James L. Rudd (AFFDL/FBE) served as technical monitor. The authors gratefully acknowledge the many contributions by Mrs. Susan French of the Aeroelastic and Structures Research Laboratory. Mrs. French was involved with the detailed programming aspects of the work throughout the entire project. This report is the third in a series, covering research conducted during February-April 1975, and was submitted for technical review in May 1975. The other reports in the series are AFFDL-TR-75-51 (Fracture Mechanics Analysis of an Attachment Lug), AFFDL-TR-75-70 (Fracture Mechanics Analysis of Centered and Offset Fastener Holes in Stiffened and Unstiffened Panels Under Uniform Tension), and AFFDL-TR-76-12 (Numerical Computation of Stress Intensity Factors for Aircraft Structural Details by the Finite Element Method). The contractor's report number is ASRL TR 177-3.

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Section 1

INTRODUCTION

This is the third of a series of reports on the development of finite-element analysis procedures for computation of linear elastic stress intensity factors associated with cracks in common aircraft structural details. The first report in the series [1] reviewed the foundations of the assumed-stress hybrid finite-element method and its application to the formulation of a special element which contains a crack-tip singularity, but which is also compatible with conventional assumed-displacement elements along its boundaries. The second report [2] documented some additions to the ASRL FEABL-2 software for substructure analysis, the development of a new hybrid element to connect the vicinity of a fastener hole to a cartesian panel geometry, and the program codes for several pieces of substructure which were put together to model a tension panel with a single fastener hole. Performance tests which were conducted on the new hybrid element demonstrated, among other things, that the element could function accurately at a fastener hole subjected to a cosine bearing pressure distribution applied either directly to the hybrid element or to the inner boundary of some rings of quadrilateral elements inserted between the hybrid element and the fastener hole surface. In the present report, the pieces and parts are shuffled and presto!--two new finite-element models appear. They are tension panels with either a single row of fastener holes, or a double row of holes on staggered centerlines. A new procedure

is introduced for each model: SBL and DBL, which generate the far-field substructures. However, the new procedures are executives which merely use the previously developed basic substructures to create different design details and different loading. The fastener hole rows are now located along the top edge of the panel, and tension is introduced by a cosine bearing pressure distribution at each hole.

Section 2

SROW AND DROW PROGRAMS

Parametric codes designated SROW and DROW have been developed to generate and analyze the single- and double-fastener-row panels. Programs SROW and DROW are executive controllers which direct procedures SBL and DBL,respectively, as well as other previously developed procedures.

2.1 Model and Input Conventions for Program SROW

Fig. 1 illustrates the structure which is modeled by program SROW: a skin panel with a horizontal row of equally spaced fastener holes near the top edge. The centerline of the row is placed below the edge by half the center-to-center spacing of the fasteners. The panel may have up to 10 holes. The bottom edge of the panel is restrained. Load is introduced by fastener bearing forces applied at the holes. These forces are represented by cosine pressure distributions. The bearing forces may be different for different fastener holes. The model assumes that one fastener hole is damaged. The user specifies the location of the damaged hole, whether it has a single crack or two cracks 180 degrees apart, and the range of angular crack positions to be analyzed.

Fig. 2 summarizes the input data card conventions. Five or six input data cards are required to supply the following information:

1. Panel Parameters

   NHOLES = Number of fastener holes in panel

   CLSPC = Center-to-center hole spacing

RI = Hole radius

IDMGD = Position of the damaged hole

LENGTH = Total length of the panel

THK = Panel thickness

2. Load Parameters

$BFORCE_i$ = Total bearing force to be applied to the i^{th} hole in the row

(Note: these data are continued on a second card for panels with NHOLES > 8.)

3. Crack Parameters

A(1) = Length of first crack

A(2) = Length of second crack

IPOS(1) = Initial position number of first crack

IPOS(2) = Final position number of first crack

4. Material Properties

E = Young's modulus

ν = Poisson's ratio

5. Print Control Parameters

KT1 = Control for optional FEABL-2 output

KT2 = Control for procedure SBL output

KT3 = Control for procedure RING output

Any value from 1 to 10 may be chosen for NHOLES. The fastener hole radius is restricted to: CLSPC/12 $\leq$ RI $\leq$ CLSPC/8. The fastener holes are considered to be in the sequence 1,2,..., NHOLES from

left to right. The damaged hole is defined by its sequence number:

$$1 \leq \text{IDMGD} \leq \text{NHOLES} \qquad (1)$$

The panel width is computed internally as NHOLES * CLSPC by program SROW.

Bearing forces for each fastener hole are specified individually on the second data card, with a continuation card required if the panel has 9 or 10 holes. The bearing force values may be zero or positive. Negative values (i.e., compressive load transfer) can be processed by the program, but will be incorrectly applied as a distributed tension on the upper half of the hole rather than as a bearing pressure on the lower half. Therefore, the use of negative bearing forces is not recommended for the present version of program SROW. The bearing forces are converted internally to consistent nodal forces which model a cosine pressure distribution statically equivalent to the bearing force.

Input parameters A(1), A(2) are the actual crack lengths, as measured from the edge of the fastener hole to the crack tip. The cracks are placed so as to emanate radially from the fastener hole. If a case with only one crack is to be analyzed, specify A(2) = 0.0. Crack lengths in the range:

$$0 \leq A(1),\ A(2) \leq 1.27(\text{RI}) \qquad (2)$$

are permitted. The initial and final angular positions of the first crack are controlled by the crack position numbers, in accordance with:

$$\begin{aligned} \theta_{initial} &= (\text{IPOS}(1)-1)\Delta\theta \\ \theta_{final} &= (\text{IPOS}(2)-1)\Delta\theta \qquad (3) \\ \Delta\theta &= \pi/12 \text{ rad.} = 15 \text{ deg.} \end{aligned}$$

If a second crack exists, it is always positioned 180 degrees from the first crack. Permissible values of the position numbers are:

$$\begin{aligned} 1 \le \mathrm{IPOS}(1) &\le n_{max} \\ \mathrm{IPOS}(1) \le \mathrm{IPOS}(2) &\le n_{max} \end{aligned} \tag{4}$$

where

$$n_{max} = 12 \text{ if } A(2) \neq 0.0$$

$$n_{max} = 24 \text{ if } A(2) = 0.0$$

Solutions are executed automatically for the angular positions from $\theta_{initial}$ to θ_{final} in 15-degree increments. A single solution is executed if IPOS(2) = IPOS(1).

The print control parameters may be used to delete nonessential output by setting:

KTi = FORTRAN unit number for line printer at user's computing facility.

The FORTRAN unit number is the value specified for the line printer in a FORTRAN-IV print instruction; e.g.:

```
WRITE (6,1000) A, B, C
```

(Unit number = 6)

Any other values for KTi (i = 1,2,3) will permit the nonessential output to be printed. Full output is recommended for the initial trial run when program SROW is first imported to a computing facility. Deletion of all three options is recommended for production runs.

2.2 Model and Input Conventions for Program DROW

Fig. 3 illustrates the structure which is modeled by program DROW: a skin panel with two horizontal rows of equally spaced

fastener holes near the top edge. The upper and lower rows are designated row 1 and row 2, respectively. The centerline of row 1 is placed below the top edge by half the fastener center-to-center spacing. Row 2 is staggered to the right of row 1 by half the center-to-center spacing. The panel may have up to 8 fastener holes per row. The bottom edge of the panel is restrained. Load is introduced by fastener bearing forces applied at the holes. These forces are represented by cosine bearing pressure distributions. A different bearing force may be specified for each hole. The model assumes that one fastener hole is damaged. The user specifies the location of the damaged hole, whether it has a single crack or two cracks 180 degrees apart, and the range of angular crack positions to be analyzed.

Fig. 4 summarizes the input data card conventions. Six input data cards are required to supply the following information:

1. Panel Parameters

   NHOLES = Total number of holes per row

   CLSPC = Center-to-center fastener spacing

   RI = Hole radius

   IROW = Row which contains damaged hole

   IDMGD = Position of damaged hole within row

   LENGTH = Total length of panel

   THK = Panel thickness

2. Load Parameters (Row 1)

   $BFORCE_i$ = Total bearing force to be applied to the i^{th} hole in the row

3. <u>Load Parameters (Row 2)</u>

$BFORCE_i$ = Total bearing force to be applied to the i^{th} hole in the row

4. <u>Crack Parameters</u>

A(1) = Length of first crack

A(2) = Length of second crack

IPOS(1)= Initial position number of first crack

IPOS(2)= Final position number of first crack

5. <u>Material Properties</u>

E = Young's modulus

ν = Poisson's ratio

6. <u>Print Control Parameters</u>

KT1 = Control for optional FEABL-2 output

KT2 = Control for procedure DBL output

KT3 = Control for procedure RING output

Any value from 1 to 8 may be chosen for NHOLES. The fastener hole radius is restricted to:

$$CLSPC/12 \leq RI \leq CLSPC/8 \qquad (5)$$

The fastener holes are considered to be in the sequence 1,2,..., NHOLES from left to right in each row. The location of the damaged hole is specified by row number IROW = 1 or 2 and position number within the row (Eq. 1). The panel width is computed internally by program DROW as CLSPC * (NHOLES + 0.5).

Bearing forces for each fastener hole are specified individually on the second data card for row 1 and on the third data card for

row 2. The bearing force values may be zero or positive. Negative values (i.e., compressive load transfer) can be processed by the program, but will be incorrectly applied as a distributed tension on the upper half of the hole rather than as a bearing pressure on the lower half. Therefore, the use of negative bearing forces is not recommended for the present version of program DROW. The bearing forces are converted internally to consistent nodal forces which model a cosine pressure distribution statically equivalent to the bearing force.

The crack parameters and print control parameters are defined in the same manner and subject to the same restrictions as for program SROW. See the latter part of Subsection 2.1 for details.

2.3 Required Subprograms and Other Features

Programs SROW and DROW require the following subprograms for execution:

1. ASRL FEABL-2 subroutines ASMLTV, ASMSUB, BCON, FACT, ORK, QBACK, SETUP, SIMULQ, STACON, and XTRACT.
2. IBM Scientific Subroutine Package subroutines MFSD and SINV.
3. ASRL elements PCRK59 and QUAD4.
4. Procedures HOLEL, LUG, and RING, together with their associated subroutines.
5. Procedure SBL (for program SROW) or procedure DBL (for program DROW).

No external (disk or tape) files are required by either program.

The core memory requirements are as follows:

Program SROW	Program DROW	
272	344	KBYTES
$68{,}000_{10}$	$86{,}000_{10}$	Decimal Words
$204{,}640_{8}$	$247{,}760_{8}$	Octal Words

Execution times range from 0.25 to 1.5 CPU minutes, depending upon the range of crack parameters investigated. The above statistics are based on program code generated by IBM FORTRAN-G1 and FORTRAN-H compilers, with demonstration runs made on an IBM 370/168 computer.

Programs SROW and DROW are supplied ready to execute on systems with IBM-standard FORTRAN unit members for the card reader (unit 5) and line printer (unit 6). The programs may be modified for other systems simply by changing the statements:

```
.
.
.
KR = 5
KW = 6
.
.
.
```

to the proper unit numbers. These statements appear near the beginning of the SROW and DROW MAIN programs.

2.4 Model Generation and Program Flow

The panel finite-element models are subdivided into two major components: the immediate neighborhood of the damaged fastener hole and the remainder of the structure. The region near the damaged hole is generated by procedure RING as an annulus substructure with boundary nodes on its inner and outer circumferences. The remainder of the structure is generated by procedure SBL or procedure DBL and statically condensed for coupling to the outer circumference of the ring.

2.4.1 Procedure SBL

Fig. 5 illustrates the hierarchy and numbering convention for the substructure generated by procedure SBL. Procedure HOLEL is used to generate the region around each fastener hole. Two calls to HOLEL are required: one for the undamaged holes for which the inner boundary of HOLEL is set at R_O = RI, and one for the damaged hole for which R_O = 2.52 (RI) to accommodate the ring. The undamaged HOLEL is assembled repeatedly. Procedure LUG is used to generate the lower portion of the panel.

The following node numbering scheme has been adopted to facilitate automatic generation of the substructure interconnections while satisfying the requirement that the boundary nodes be numbered last to permit static condensation:

1. The HOLEL inner boundaries are numbered first, in the left-to-right sequence corresponding to the hole position. Thus, nodes 1 to 24 are placed in the first HOLEL, nodes 25 to 48 in the second, etc.

2. The mid-edge nodes on the fastener row centerline, the fastener row upper edge nodes, and the fastener row lower edge* nodes are numbered in order, from right to left. Fictitious nodes are included at the hole centers to facilitate the numbering algorithm. These are later restrained without having received any stiffnesses during the assembly.

3. Finally, 24 additional node numbers are assigned to the inner boundary of the damaged HOLEL, and the original node numbers are reassigned to the lower edge of the LUG substructure. Some of the latter will be left over, and are, therefore, restrained without receiving stiffnesses.

The node numbers shown in Fig. 5 are the final assignments for a case in which the third in a row of three fastener holes is damaged.

---

*The lower edge node numbers are also assigned to the upper edge of the LUG substructure.

The various substructures are now assembled and the fictitious nodes are restrained. The bottom edge of the panel is also restrained and nodal forces representing the bearing loads are applied at the undamaged holes, as indicated in Fig. 5. Finally, the assembled substructure is statically condensed to a "Cheshire Cat" (nothing left but the smile), consisting of the 24 nodes on the damaged HOLEL inner boundary, ready for final assembly.

2.4.2 Procedure DBL

Fig. 6 illustrates the hierarchy and numbering convention for the substructure generated by procedure DBL. The model creation is generally similar to what has just been described, the only significant differences being some details of the node numbering pattern and the inclusion of QUAD4 elements in the assembly to account for the stagger between the two fastener rows. The end product of procedure DBL is another Cheshire Cat, ready for final assembly.

2.4.3 Executive Flow

Programs SROW and DROW have the same executive flow, summarized in Fig. 7. The input data are read and printed for reference, and procedure SBL or procedure DBL is called to create the appropriate Cheshire Cat. The Cheshire Cat is designated as substructure 1 for the final assembly. At this point, the process of setting up the final substructure is started. A re-entry point appears in the midst of the interconnection generation algorithm (statement 205 in either program) to permit the band-margin computation subroutine (ORK) to erase the $\underset{\sim}{K}$ and $\underset{\sim}{q}$ data from the previous analysis.

The Cheshire Cat is now assembled, and procedure RING is used to generate the cracked ring (substructure 2), which is also assembled. Nodal forces for the bearing load on the damaged hole are now applied, and a global displacement solution is obtained for the structure. Finally, a back-substitution solution is executed for the cracked ring, displacements $\underset{\sim}{q}_L$ are extracted for one or two PCRK59 elements, and NASA/ASTM-standard stress intensity factors K_I and K_{II} are computed. Logical IF statements at the end of the loop determine whether the angular crack position is to be incremented for another analysis. If another case remains to be analyzed, the crack angle is incremented and the program branches back to the re-entry point at statement 205.

2.5 Output Conventions and Error Messages

Fig. 8 illustrates a sample output from program DROW with all optional printout deleted. The heading identifies the program which was executed and repeats the user's input data for checking. Below the heading appears a table giving the angular position, K_I and K_{II} for each crack. If the input data have been given in units of lbs. for bearing force, psi for Young's modulus and inches for dimensions, K_I and K_{II} are in units of psi $\sqrt{in}$. The crack angles are given in degrees. The output from program SROW is similar.

Error messages printed by procedure RING and by the FEABL-2 software have been documented elsewhere [2,3]. In addition, procedures SBL and DBL print error messages and terminate execution if the restriction given by Eq. 5 is violated. Finally, programs SROW and DROW print warning messages, change the panel length, and

continue execution if the user has input a length too short compared to the center-to-center spacing of the fasteners. The programs are always executed with:

$$\begin{aligned} &\text{LENGTH} \geq 2\ (\text{CLSPC})\ \text{for program SROW} \\ &\text{LENGTH} \geq 3\ (\text{CLSPC})\ \text{for program DROW} \end{aligned} \qquad (6)$$

2.6 Status of Programs

Programs SROW and DROW are maintained as 029-punched FORTRAN-IV source decks, sequenced by individual subroutine. All input options described in subsections 2.1 and 2.2 have been exercised successfully for panels containing up to three fastener holes per row. Source listings appear in Appendix A for program SROW and procedure SBL, and in Appendix B for program DROW and procedure DBL. Listings for the other procedures appear in a previous report in this series [2].

Section 3

DEMONSTRATION EXAMPLES

Figure 9 illustrates an example of a single row of three fastener holes, each loaded by a 1,000-lb. bearing force in a 1-inch thick panel. Sample analyses of this structure were run with the center and right holes damaged by a single crack. Butterfly plots for K_I and K_{II} are presented in Fig. 10 (center hole damaged) and Fig. 11 (right hole damaged). The observed behavior is similar to solutions for cosine bearing loading applied to an attachment lug detail [1]. In particular, maxima for K_I are seen to occur for cracks at $\pm$ 105 degrees from the line of action of the applied load (θ = 195 and 345 degrees), in the symmetric case (Fig. 10), and significant K_I values occur for cracks on the load line (θ = 90 degrees) due to the local hoop tension effect of the bearing pressure. Asymmetric behavior is evident for both K_I and K_{II} in the case of the right hole damaged (Fig. 11). A curious result for this case is that the maximum K_I occurs when the crack is positioned away from the neighboring fastener hole (θ = 345 degrees).

Figure 12 illustrates an example problem for a similar structure with two rows of fasteners. The results of two example analyses of this structure are plotted in Figs. 13 and 14. In Fig. 13, the center hole in the upper row is damaged. These results are comparable to the behavior of the single-row cases, except that asymmetry is now introduced by the presence of the second row of fasteners. Also, the maxima of K_I now shift downward toward the second fastener row. In Fig. 14, the center hole in the lower row is damaged. Comparison with Fig. 13 shows that K_I and K_{II} have increased roughly by a factor

of 2, an effect which may be attributed to the fact that the damaged hole is located deeper in the load-transfer zone of the structure. Solution asymmetry is very slight for this case.

Section 4

DISCUSSION AND CONCLUSIONS

Unfortunately, there exist no independent K_I solutions for cracks at fastener holes loaded in bearing. However, some approximate correlations can be made by comparison with solutions available for similar problems, if the bearing forces are translated into average tension for the nominal cross section of the panel. The conversions are given by:

$$\begin{aligned} \sigma_1 &\simeq 3 \times 1{,}000 \text{ lb.}/30 \text{ in}^2 = 100 \text{ psi} \\ \sigma_2 &\simeq 6 \times 1{,}000 \text{ lb.}/35 \text{ in}^2 = 171.5 \text{ psi} \end{aligned} \tag{7}$$

for the single- and double-row cases, respectively. Thus, one might logically expect to find, e.g.,:

$$K_I \text{ (Fig. 14)}/K_I \text{ (Fig. 10)} = 1.715 \tag{8}$$

for a given crack angle, together with a similar result for K_{II}. The following summary of calculations tends to confirm the expected behavior:

Item	From Fig. 10	From Fig. 14	Ratio	% Error
K_I at $\theta = 0°$	250 psi $\sqrt{in}$	431 psi $\sqrt{in}$	1.72	0.3
K_I at $\theta = 180°$	250	436	1.74	1.5
K_{II} at $\theta = 210°$	181	324	1.79	4.4
K_{II} at $\theta = 330°$	181	320	1.77	3.2

An approximate comparison may also be made with published solutions for cracks in an infinite plate under uniform tension [4]:

$$K_I(\theta=0°) = \frac{\sigma\sqrt{4b}\,\sin\left(\frac{\pi c}{2b}\right)}{\sqrt{\sin\left(\frac{\pi c}{b}\right)}} \tag{9}$$

for a row of repeated cracks, or:

$$K_I(\theta=0°) = \sigma\sqrt{\pi a}\ F\ (a/R_I) \tag{10}$$

for a single crack emanating from a single hole. The quantities a,b,c,R_I are defined in Fig. 15. For the present case, the results of the comparison are as follows:

Program	Computed K_I	K_I (Eq. 9)	K_I (Eq. 10)
SROW (Fig. 10)	250	246	271
DROW (Fig. 14)	431-436	421	465

where the stresses σ_1, σ_2 given by Eqs. 7 have been used in Eq. 9 and Eq. 10. The fact that the computed K_I values are below the classical solution for a crack at a hole may be attributed to incomplete development of the nominal tension in the immediate vicinity of the fastener bearing load. Also, it is comforting to note that the finite-element results are bounded by the two classical solutions, within a range of about 10 percent.

The results presented in this report demonstrate that the assumed-stress hybrid finite element method is capable of providing stress intensity factor solutions for a wide variety of structural details. The specific program codes documented in this report treat panels loaded by bearing through a single row or a double staggered row of fastener holes near one edge of the panel. The programs are presently restricted to fairly widely spaced fasteners, in order to remain in the parameter ranges for which the most accurate performance of the individual finite elements was demonstrated in earlier work.

This restriction and an approximate comparison of the computed results with classical solutions indicate that the finite-element computations for K_I and K_{II} are within 5 to 10 percent of the exact answers. A better error assessment does not seem likely in the near future because of the difficulty in obtaining classical solutions for the very complicated geometry and loading associated with these structural details. Only a few demonstration examples have been presented, but the possibilities for these programs are legion. Situations in which the bearing load varies from one fastener to another may be of interest to the detail designer. One extremely interesting example is the question of stress intensity at a hole which has cracked sufficiently to unload its fastener. Will this result in crack arrest, or will the bearing loads from nearby fasteners still impose a K_I great enough to continue crack growth or to cause fracture? This and other example solutions will be presented in the final report in this series.

REFERENCES

1. Orringer, O., "Fracture Mechanics Analysis of an Attachment Lug", Aeroelastic and Structures Research Laboratory, MIT, ASRL TR 177-1, AFFDL-TR-75-51, December 1974.

2. Stalk, G. and Orringer, O., "Fracture Mechanics Analysis of Centered and Offset Fastener Holes in Stiffened and Unstiffened Panels under Uniform Tension", Aeroelastic and Structures Research Laboratory, MIT, ASRL TR 177-2, AFFDL-TR-75-70, April 1975.

3. Orringer, O. and French, S. E., "FEABL (Finite Element Analysis Basic Library) User's Guide", Aeroelastic and Structures Research Laboratory, MIT, ASRL TR 162-3, AFOSR-TR-72-2228, August 1972. (Supplemented by ASRL TM 162-3-3 and ASRL TM 162-3-4, February 1974.)

4. Paris, P. C. and Sih, G. C., "Stress Analysis of Cracks", ASTM STP 381, Fracture Toughness Testing and Its Applications, 1965, pp. 30-83.

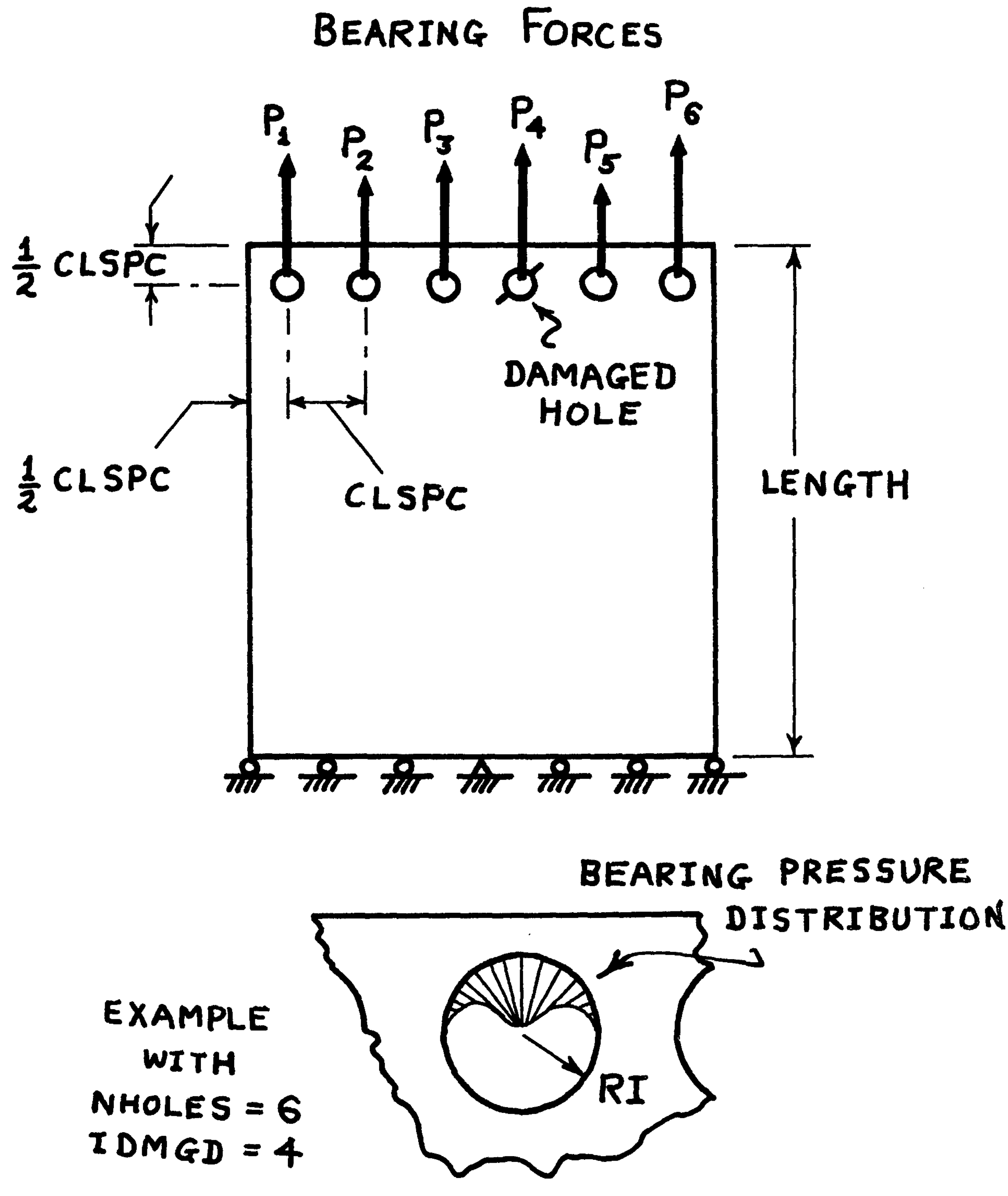


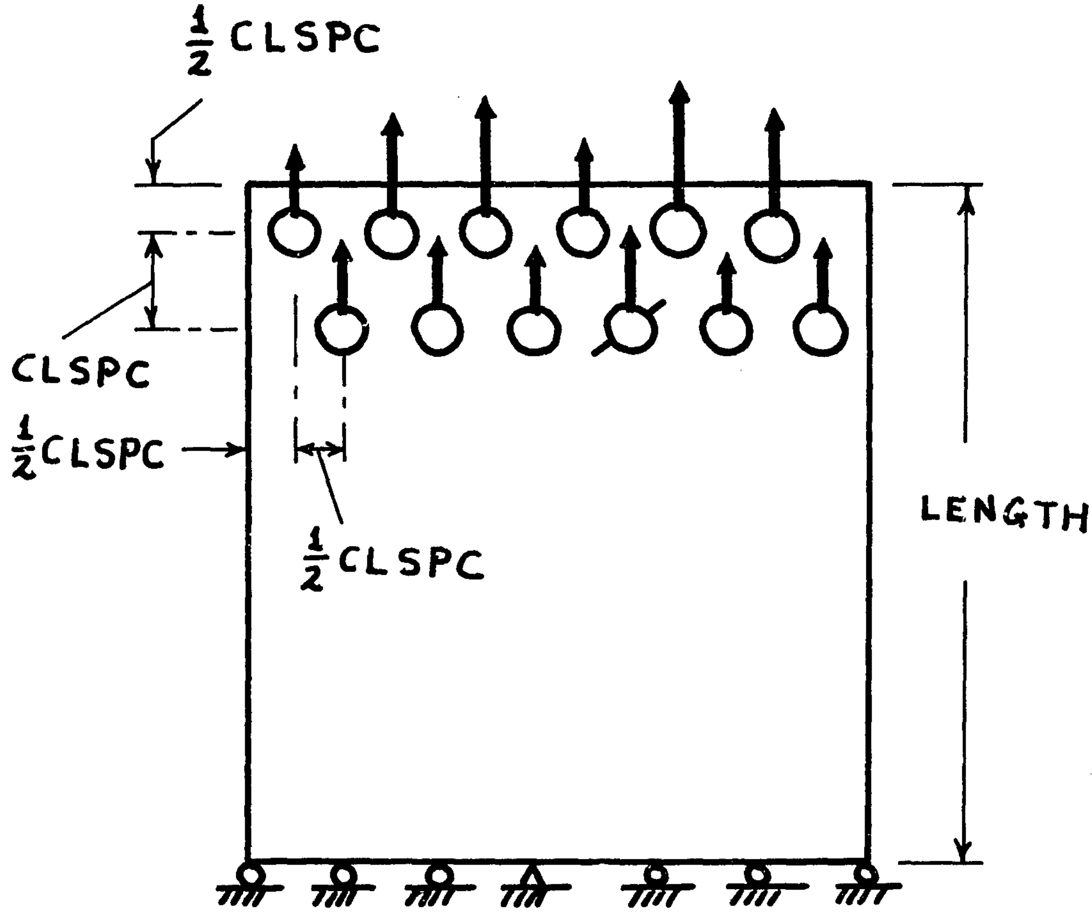
FIG. 1 STRUCTURE MODELED BY PROGRAM SROW

JOB TITLE PROGRAM SROW - INPUT DATA CONVENTIONS ENGINEER STALK/ORRINGER

JOB NO. 81739 PROGRAMMER FRENCH DATE 1 APRIL 1975 SHEET 1 OF 1

CARD #	1–80
1	NHOLES | CLSPC | RI | IDMGD | LENGTH | THK
	(I5, 2E10.3, I5, 2E10.3)
2	$BFORCE_1$ | $BFORCE_2$ | $BFORCE_3$ | $BFORCE_4$ | $BFORCE_5$ | $BFORCE_6$ | $BFORCE_7$ | $BFORCE_8$
	(8E10.3)
2 (con't)	$BFORCE_9$ | $BFORCE_{10}$ | Continuation card, if req'd.
	(2E10.3)
3	A(1) | A(2) | IPOS(1) | IPOS(2)
	(2E10.3, 2I5)
4	E | ν
	(2E10.3)
5	KT1 | KT2 | KT3
	(3I5)

FIG. 2 INPUT CONVENTIONS FOR PROGRAM SROW



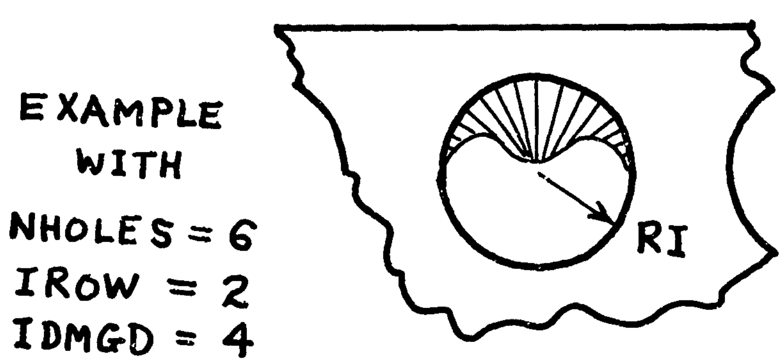


FIG. 3 STRUCTURE MODELED BY PROGRAM DROW

JOB TITLE: PROGRAM DROW - INPUT DATA CONVENTIONS

ENGINEER: STALK/ORRINGER

JOB NO.: 81739

PROGRAMMER: FRENCH

DATE: 1 APRIL 1975

SHEET: 1 OF 1

CARD #	1–80
1	NHOLES (cols 1–5) | CLSPC (6–15) | RI (16–25) | IROW (26–30) | IOMGD (31–35) | LENGTH (36–45) | THK (46–55) (I5, 2E10.3, 2 x I5, 2E10.3)
2	BFORCE$_1$ | BFORCE$_2$ | BFORCE$_3$ | BFORCE$_4$ | BFORCE$_5$ | BFORCE$_6$ | BFORCE$_7$ | BFORCE$_8$ (8E10.3) Bearing loads for row #1
3	BFORCE$_1$ | BFORCE$_2$ | BFORCE$_3$ | BFORCE$_4$ | BFORCE$_5$ | BFORCE$_6$ | BFORCE$_7$ | BFORCE$_8$ (8E10.3) Bearing loads for row #2
4	A(1) | A(2) | IPOS(1) | IPOS(2) (2E10.3, 2I5)
5	E | ν (2E10.3)
6	KT1 | KT2 | KT3 (3I5)

FIG. 4 INPUT CONVENTIONS FOR PROGRAM DROW

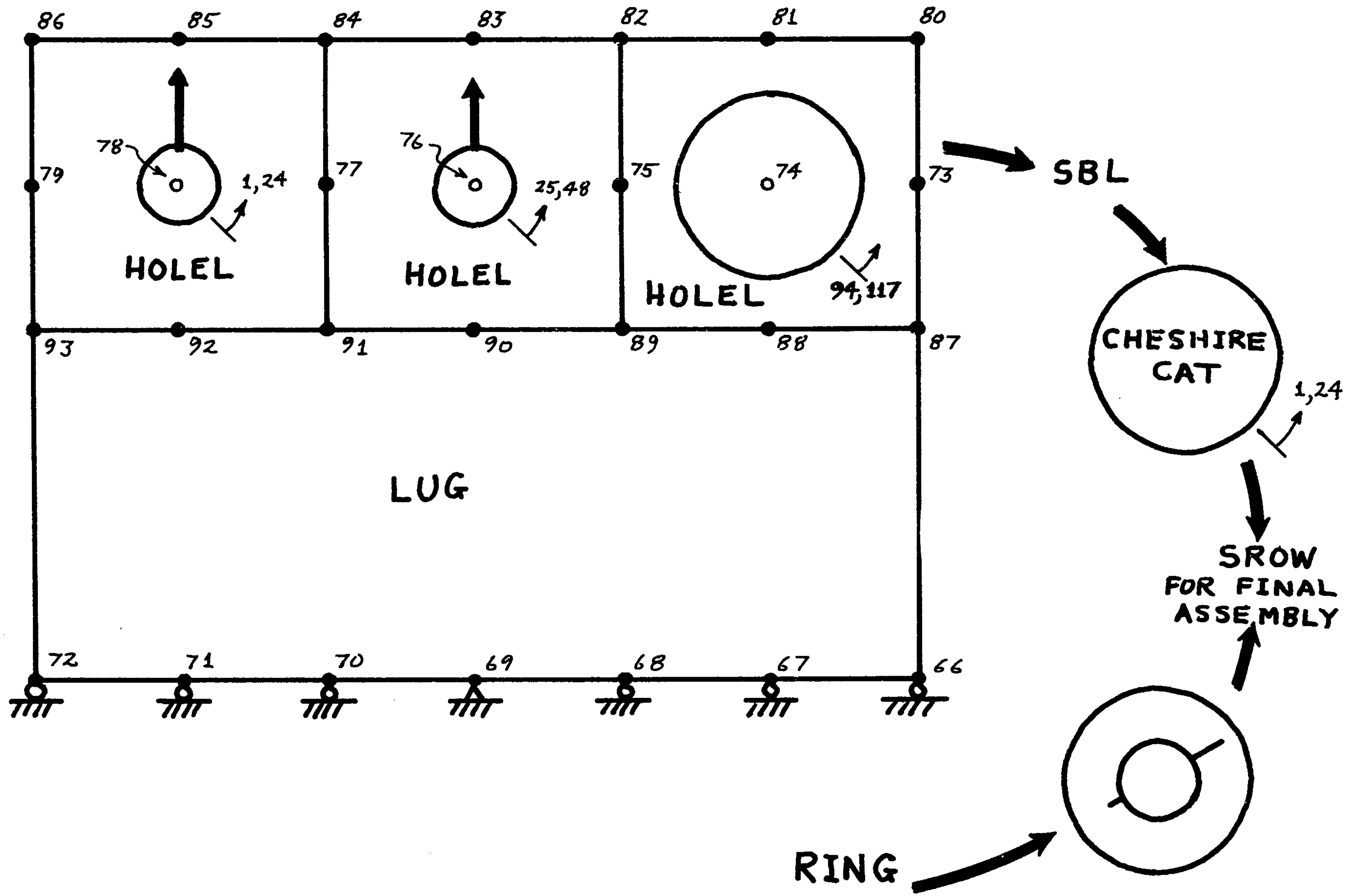


FIG. 5 SUBSTRUCTURE HIERARCHY (PROCEDURE SBL)

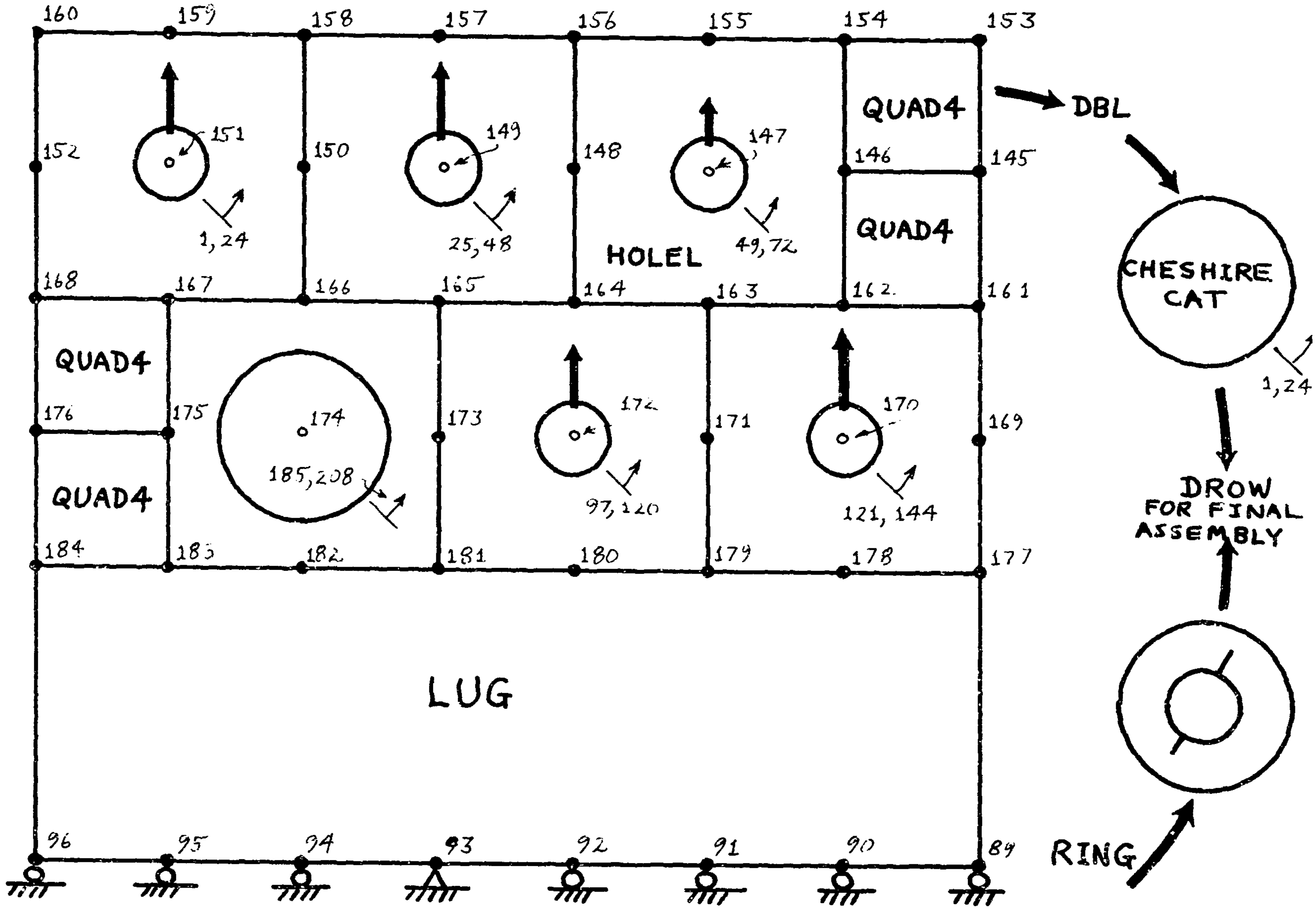


FIG. 6 SUBSTRUCTURE HIERARCHY (PROCEDURE DBL)

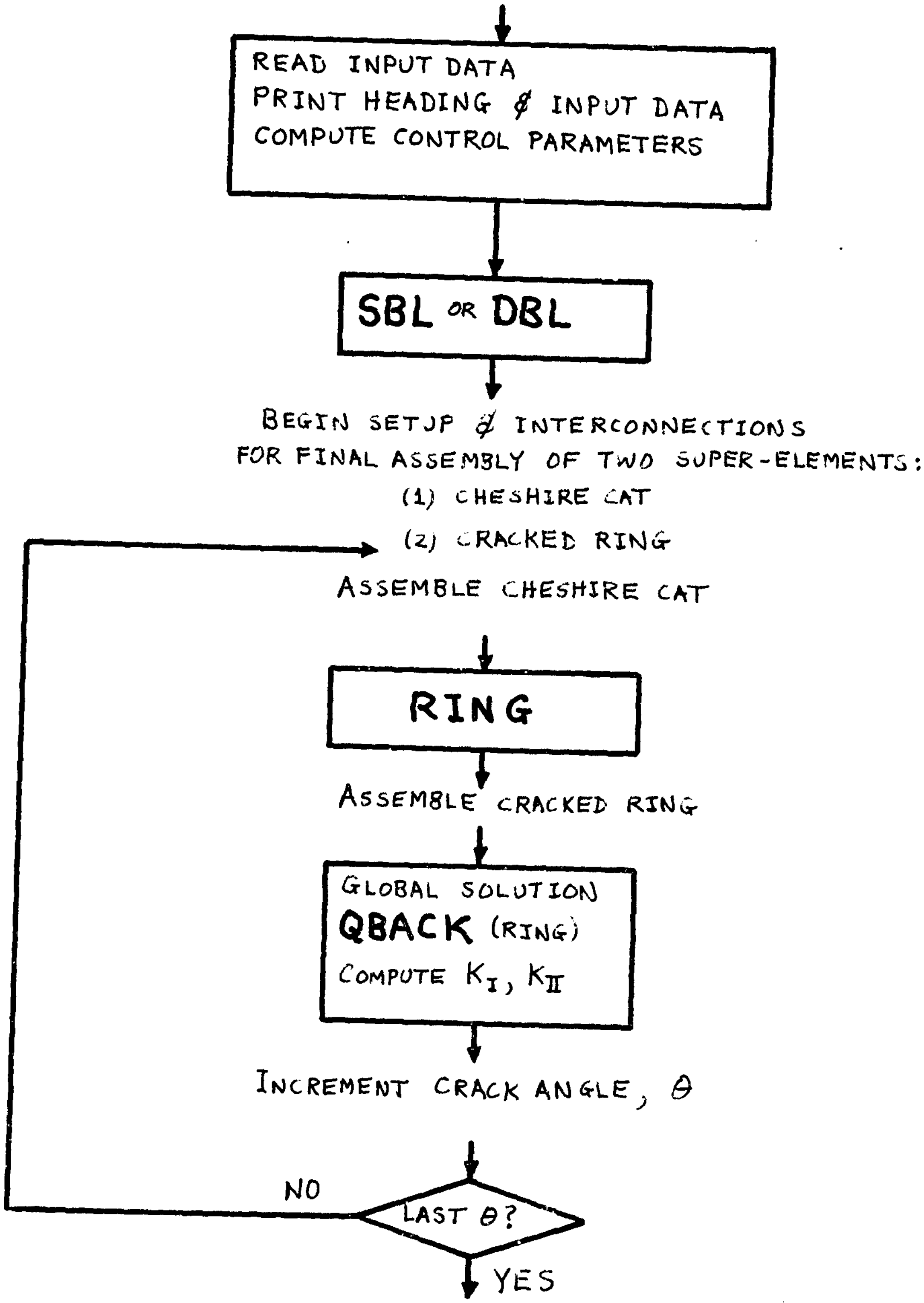


FIG. 7 EXECUTIVE FLOW (PROGRAM SROW OR PROGRAM DROW)

```
                                   DOUBLE BOLT LINE

                                    PROBLEM NO. 6

                                     INPUT DATA
NUMBER OF HOLES PER ROW=  3
CENTER LINE SPACING OF HOLES= 0.10000E+02
BEARING HOLE RADIUS= 0.12500E+01
DAMAGED HOLE IN ROW 2 IS  2 FROM L.H.S.
PLATE LENGTH= 0.30000E+02
PLATE WIDTH= 0.35000E+02
PLATE THICKNESS= 0.10000E+01
BEARING LOADS :    HOLE        FORCE(LBS)
          ROW= 1     1        0.10000E+04
          ROW= 1     2        0.10000E+04
          ROW= 1     3        0.10000E+04
          ROW= 2     1        0.10000E+04
          ROW= 2     2        0.10000E+04
          ROW= 2     3        0.10000E+04

CRACK DATA:
TOTAL NUMBER OF CRACKS= 1
CRACK NO.     CRACK LENGTH

        1     0.12500E+01

INITIAL CRACK POSITION=   0.0      FINAL CRACK POSITION= 345.000   (+180 DEGREES FOR CRACK NO. 2 POSITION)

MATERIAL PARAMETERS:
YOUNGS MODULUS (E)= 0.10000E+08
POISSONS RATIO=   0.300

CRACK NO.  1  ANGLE=   0.0       KI= 0.43142E+03    KII= 0.31922E+02

CRACK NO.  1  ANGLE=  15.000     KI= 0.42213E+03    KII= 0.15192E+03

CRACK NO.  1  ANGLE=  30.000     KI= 0.39588E+03    KII= 0.27088E+03

CRACK NO.  1  ANGLE=  45.000     KI= 0.30798E+03    KII= 0.25876E+03

CRACK NO.  1  ANGLE=  60.000     KI= 0.20125E+03    KII= 0.19908E+03

CRACK NO.  1  ANGLE=  75.000     KI= 0.11763E+03    KII= 0.10212E+03

CRACK NO.  1  ANGLE=  90.000     KI= 0.88530E+02    KII= 0.63011E+01

CRACK NO.  1  ANGLE= 105.000     KI= 0.10430E+03    KII= 0.92770E+02

CRACK NO.  1  ANGLE= 120.000     KI= 0.18474E+03    KII= 0.19904E+03

CRACK NO.  1  ANGLE= 135.000     KI= 0.29877E+03    KII= 0.26816E+03
```

FIG. 8 SAMPLE OUTPUT (PROGRAM DROW)

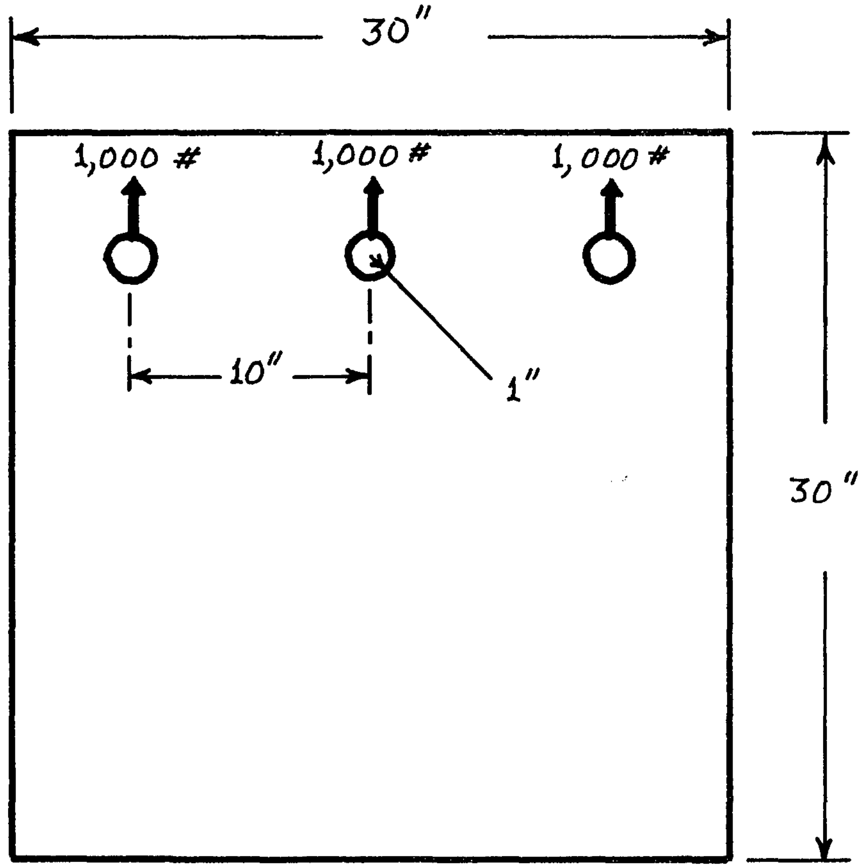


FIG. 9 EXAMPLE OF PANEL WITH ONE ROW OF THREE FASTENER HOLES

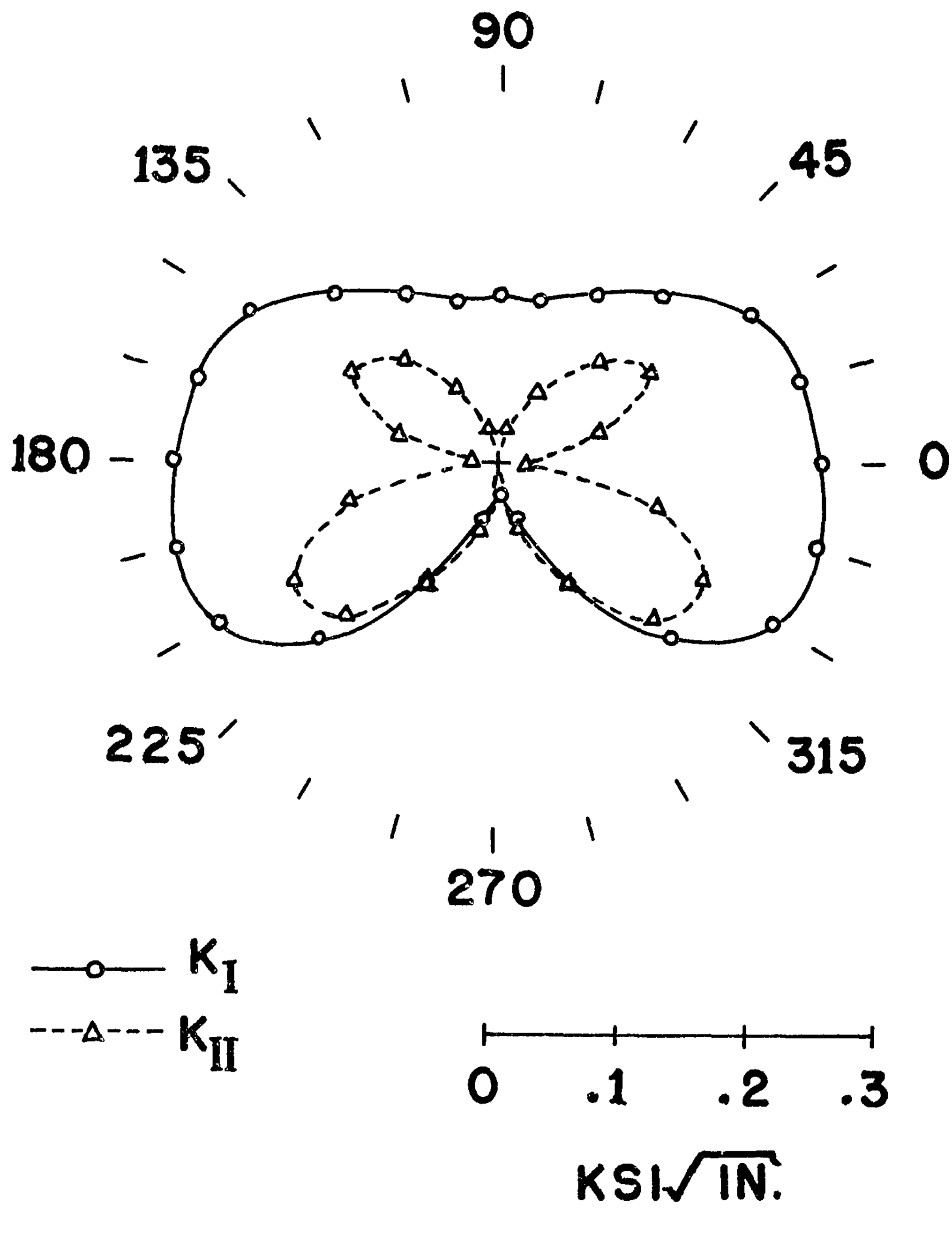


FIG. 10 BUTTERFLY PLOT (CENTER HOLE DAMAGED)

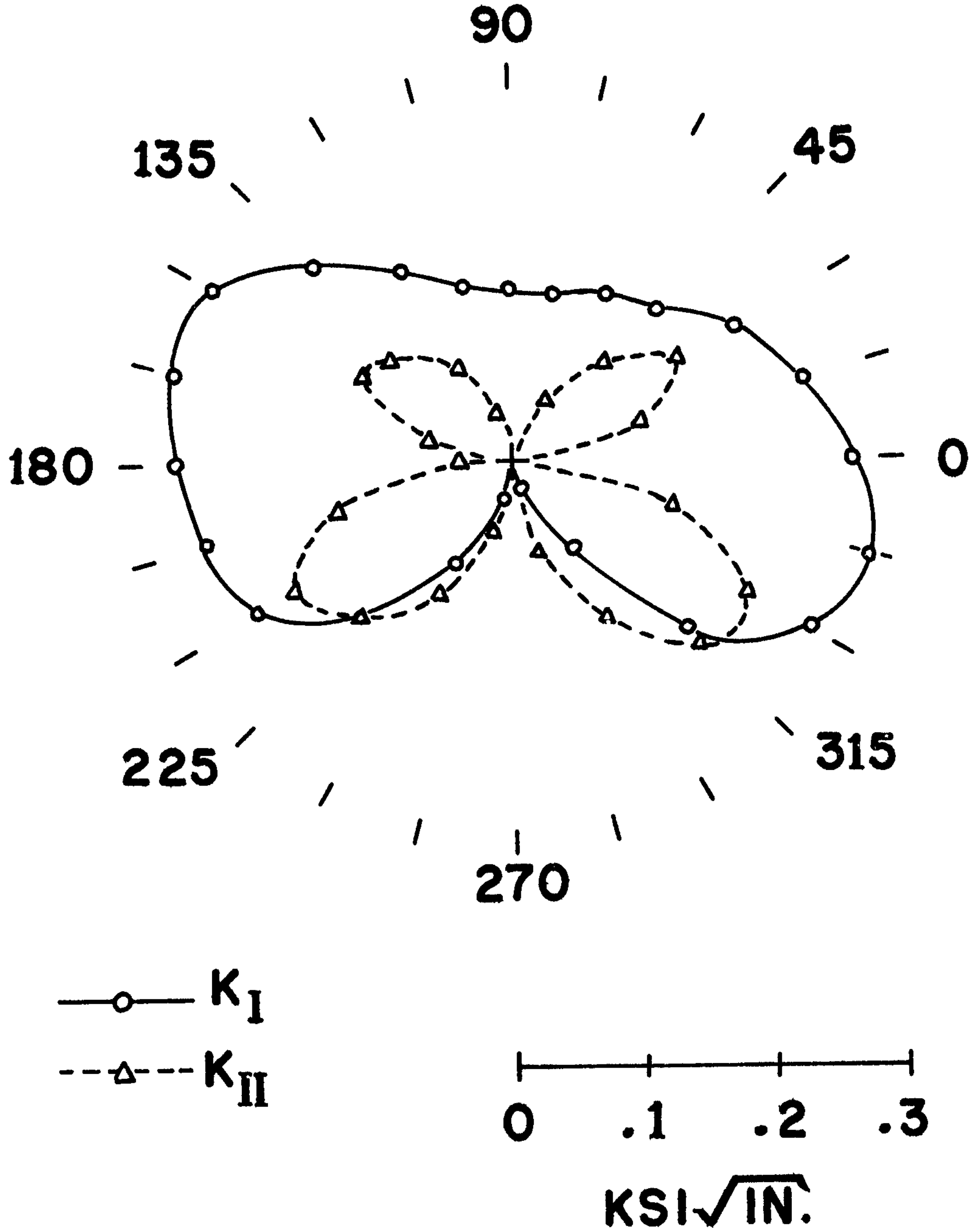


FIG. 11 BUTTERFLY PLOT (RIGHT HOLE DAMAGED)

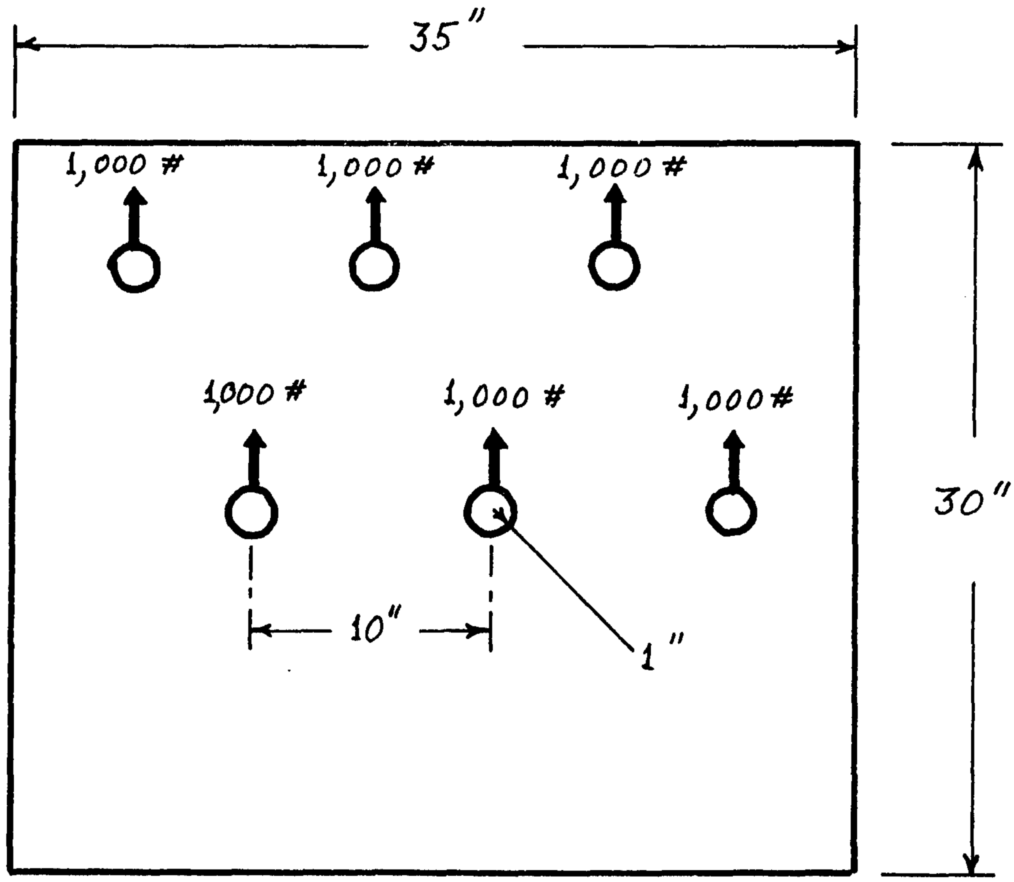


FIG. 12 EXAMPLE OF PANEL WITH TWO ROWS OF THREE FASTENER HOLES

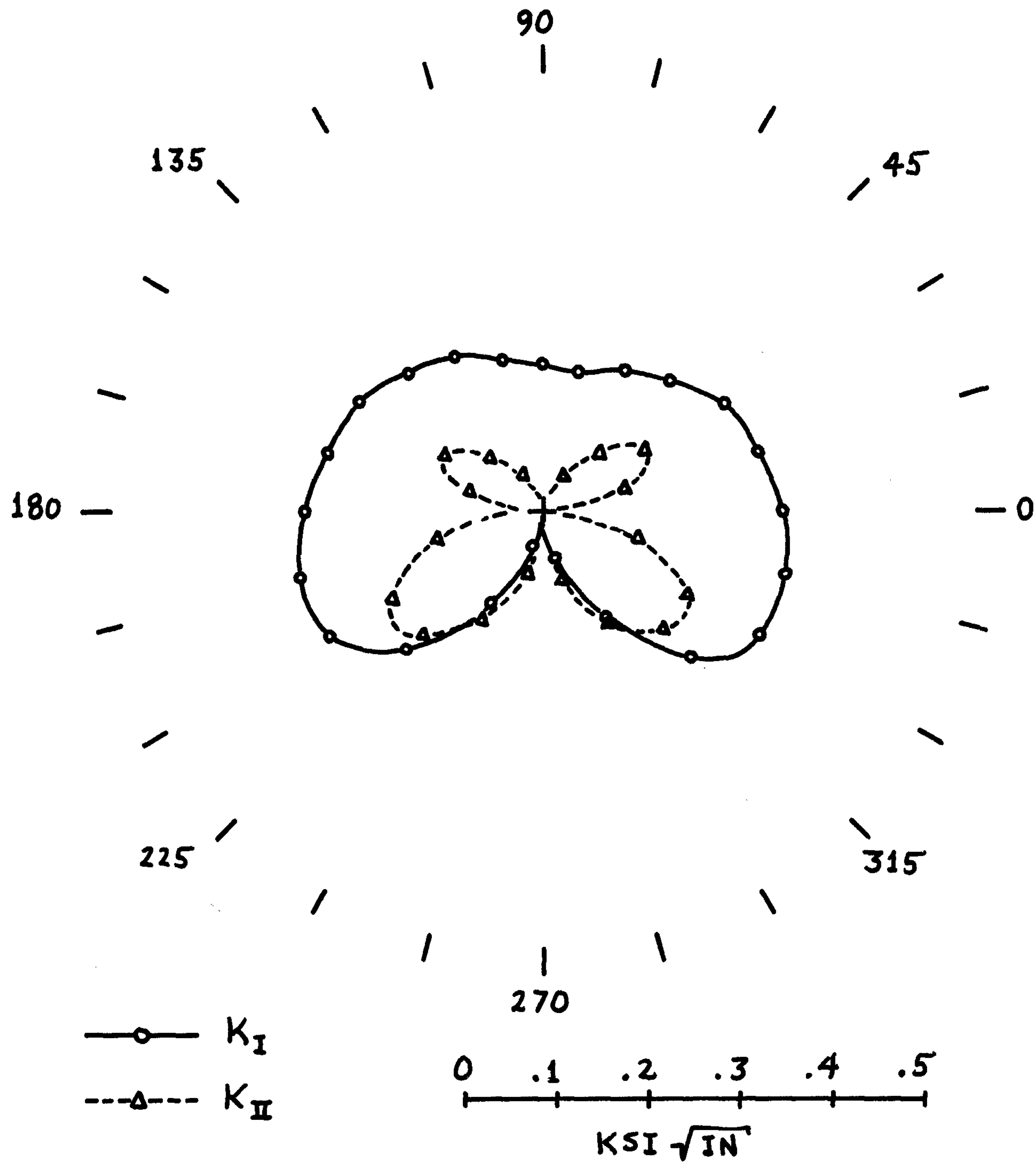


FIG. 13 BUTTERFLY PLOT (CENTER HOLE IN UPPER ROW DAMAGED)

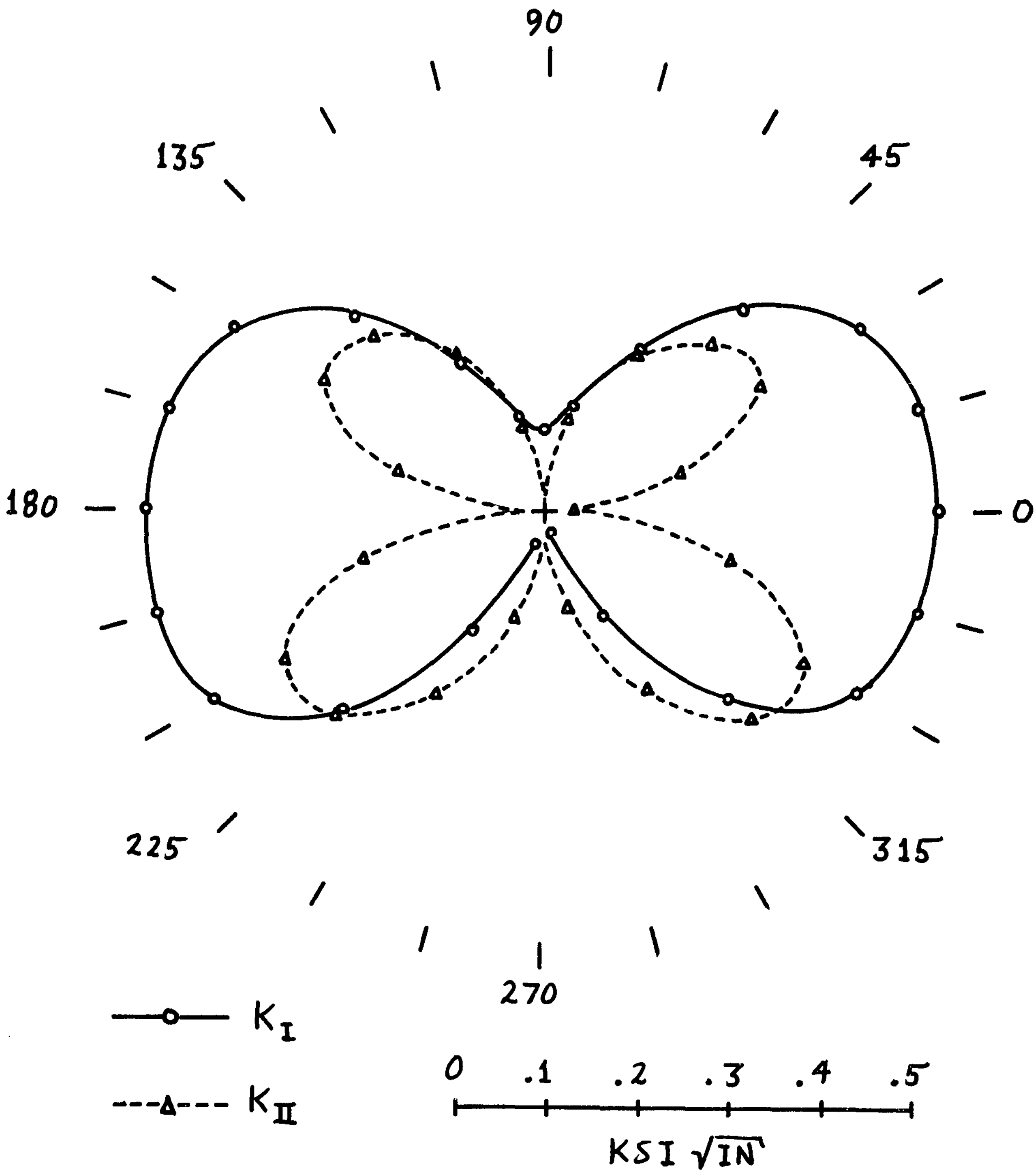


FIG. 14 BUTTERFLY PLOT (CENTER HOLE IN LOWER ROW DAMAGED)

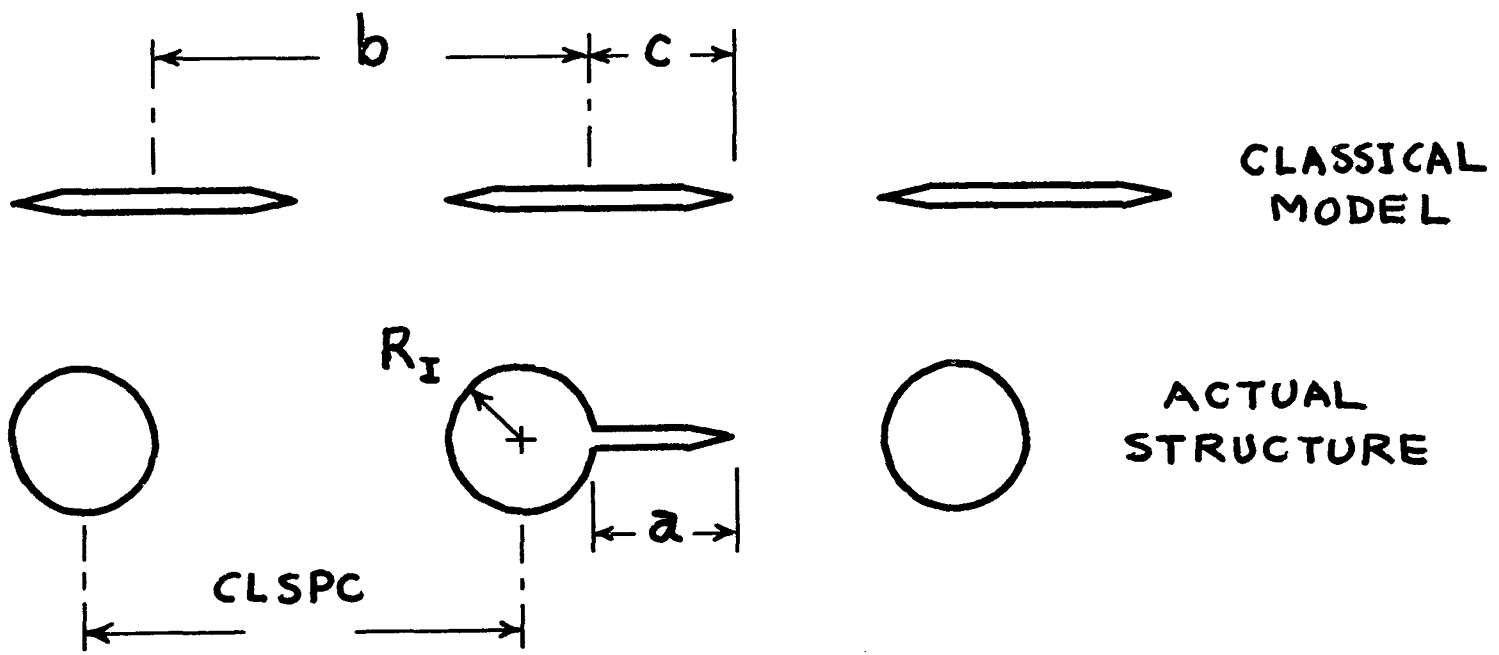


FIG. 15 DEFINITION OF CRACK PARAMETERS FOR CLASSICAL SOLUTIONS

APPENDIX A

```
C  TEST MAIN FOR SINGLE ROW OF BOLT HOLES (SROW)                        SROW0001
C***********************************************************************SROW0002
C COPYRIGHT (C) 1975 MASSACHUSETTS INSTITUTE OF TECHNOLOGY              SROW0003
C AEROELASTIC AND STRUCTURES RESEARCH LABORATORY                        SROW0004
C***********************************************************************SROW0005
C FINITE ELEMENT APPLICATIONS TO USAF STRUCTURAL INTEGRITY PROBLEMS     SROW0006
C........INPUT DATA FOR PROBLEM #5 - SINGLE ROW OF BOLT HOLES...........SROW0007
C SET        VARIABLES IN SET                     FORMAT FOR EACH CARD  SROW0008
C  1         NHOLES,CLSPC,RI,IDMGD,LENGTH,THK      (I5,2E10.3,I5,2E10.6)SROW0009
C  2         BFORCE(I), FOR I=1,2,3...NHOLES                    (8E10.3)SROW0010
C  3         A(1),A(2),IPOS(1),IPOS(2)                      (2E10.3,2I5)SROW0011
C  4         E,GNU                                              (2E10.3)SROW0012
C  5         KT1,KT2,KT3                                         (3I5)  SROW0013
C =====DEFINITIONS OF INPUT VARIABLES===================================SROW0014
C NHOLES = NO. OF HOLES;  CLSPC = CENTER LINE SPACING OF HOLES          SROW0015
C RI = RADIUS OF HOLE;  IDMGD = POSITION NO. OF DAMAGED HOLE FROM L.H.S.SROW0016
C LENGTH = LENGTH OF PLATE;  THK = THICKNESS OF PLATE                   SROW0017
C BFORCE(I) = MULTIPLIER FOR LOAD IN HOLE I;  A(1) = LENGTH OF CRACK ONESROW0018
C A(2) = LENGTH OF CRACK NO. TWO;  IPOS(1) = INITIAL POSITION OF CRACK 1SROW0019
C IPOS(2) = FINAL POSITION OF CRACK 1; E = YOUNGS MODULUS;              SROW0020
C GNU = POISSONS RATIO;  KT1 = PRINT CONTROL FOR FEABL OPTIONAL PRINT;  SROW0021
C KT2 = PRINT CONTROL FOR OPTIONAL SBL PRINTING                         SROW0022
C KT3 = PRINT CONTROL FOR OPTIONAL RING PRINTING                        SROW0023
C***********************************************************************SROW0024
      DIMENSION RSS(12000),ISS(12000),REAL(8000),INTGR(8000),RRNG(12000)SROW0025
     @,                                                                 SROW0026
     @IRNG(12000),A(2),IPOS(2),BFORCE(10),S(3,3),C(3,3),SCALE(2,13),IBEGSROW0027
     @IN(6),IEND(6),ISZSS(3),ISZBL(3),IBGBL(6),ISAVE1(2),ISAVE2(6),ISAVESROW0028
     @3(6),ISZ(2),ELQ(18),RK(2)                                         SROW0029
      INTEGER PRNTSV                                                    SROW0030
      REAL LENGTH                                                       SROW0031
      COMMON/IO/KR,KW,KP,KT1,KT2,KT3                                    SROW0032
      COMMON/SIZE/NET,NDT                                               SROW0033
      COMMON/BEGIN/ICON,IKOUNT,ILNZ,IMASTR,IQ,IK                        SROW0034
      COMMON/END/LCON,LKOUNT,LLNZ,LMASTR,LQ,LK                          SROW0035
      COMMON/SIZESS/NETSS,NDTSS,NIDSS                                   SROW0036
```

```
      COMMON/BEGSS/IBGSS(6)                                              SROW0037
      COMMON/MTLPRM/SMU,ETA                                              SROW0038
      COMMON/KI/BCRK(2,2,18)                                             SROW0039
      EQUIVALENCE (RSS(1),ISS(1)),(REAL(1),INTGR(1)),(RRNG(1),IRNG(1)), SROW0040
     @(ISZ(1),NET),(IBEGIN(1),ICON),(IEND(1),LCON),(ISZSS(1),NETSS)     SROW0041
      DATA PI/3.141593/,C/1.0,3*0.0,1.0,4*0.0/,S/1.0,3*0.0,1.0,4*0.0/   SROW0042
      DTHETA=PI/12.0                                                     SROW0043
      SQRTPI=SQRT(PI)                                                    SROW0044
      DATA NSZSS/12000/,NSIZE/ 8000/,NSZRNG/12000/                       SROW0045
      KR=5                                                               SROW0046
      KW=6                                                               SROW0047
C  INPUT DATA:                                                           SROW0048
      READ(KR,5000) NHOLES,CLSPC,RI,IDMGD,LENGTH,THK                     SROW0049
 5000 FORMAT(I5,2E10.3,I5,2E10.3)                                        SROW0050
      READ(KR,5001) (BFORCE(I),I=1,NHOLES)                               SROW0051
 5001 FORMAT(8E10.3)                                                     SROW0052
      READ(KR,5002) A(1),A(2),IPOS(1),IPOS(2)                            SROW0053
 5002 FORMAT(2E10.3,2I5)                                                 SROW0054
      READ(KR,5003) E,GNU                                                SROW0055
 5003 FORMAT(2E10.3)                                                     SROW0056
      READ(KR,5004) KT1,KT2,KT3                                          SROW0057
 5004 FORMAT(3I5)                                                        SROW0058
      WRITE(KW,6000) NHOLES,CLSPC,RI,IDMGD                               SROW0059
 6000 FORMAT(1H1,56X,16HSINGLE BOLT LINE,//,59X,13HPROBLEM NO. 5,///,60XSROW0060
     @,10HINPUT DATA,/,17H NUMBER OF HOLES=,I3,/,30H CENTER LINE SPACINGSROW0061
     @ OF HOLES=,E12.5,/,21H BEARING HOLE RADIUS=,E12.5,/,30H DAMAGED HOSROW0062
     @LE ( FROM L.H.S. )=,I3)                                            SROW0063
      WIDTH=2.0*CLSPC                                                    SROW0064
      IF(LENGTH .GE. WIDTH) GO TO 20                                     SROW0065
      WRITE(KW,6001) WIDTH                                               SROW0066
 6001 FORMAT(29H0***** PROGRAM INTERUPT *****,/,109H USER SPECIFIED PLATSROW0067
     @E DIMENSION LENGTH IS LESS THAN ACCEPTABLE MINIMUM.   DIMENSION LESROW0068
     @NGTH WILL BE CHANGED TO ,E12.5/)                                   SROW0069
      LENGTH=WIDTH                                                       SROW0070
 20   WIDTH=NHOLES*CLSPC                                                 SROW0071
      WRITE(KW,6002) LENGTH,WIDTH,THK                                    SROW0072
```

```
6002 FORMAT(14H PLATE LENGTH=,E12.5,/,13H PLATE WIDTH=,E12.5,/,17H PLATSROW0073
    @E THICKNESS=,E12.5,/,41H BEARING LOADS :    HOLE        FORCF(LBS),SROW0074
    @/)                                                                 SROW0075
      DO 30 I=1,NHOLES                                                  SROW0076
 30   WRITE(KW,6003) I,BFORCE(I)                                        SROW0077
 6003 FORMAT(1H ,20X,I2,5X,E12.5)                                       SROW0078
      NCRK=0                                                            SROW0079
      DO 40 I=1,2                                                       SROW0080
 40   IF( A(I) .GT. 0.0) NCRK=NCRK+1                                    SROW0081
      WRITE(KW,6004) NCRK                                               SROW0082
 6004 FORMAT(12H0CRACK DATA:,/,24H TOTAL NUMBER OF CRACKS=,I2)          SROW0083
      IF(NCRK .EQ. 0 ) GO TO 50                                         SROW0084
      WRITE(KW,6005) (I,A(I),I=1,NCRK)                                  SROW0085
 6005 FORMAT(11H CRACK NO. ,3X,13H CRACK LENGTH,//,5X,I5,4X,E12.5,/,5X,ISROW0086
    @5,4X,E12.5)                                                        SROW0087
      S(3,3)=(IPOS(1)-1)*15.0                                           SROW0088
      S(2,1)=(IPOS(2)-1)*15.0                                           SROW0089
      WRITE(KW,60045) S(3,3),S(2,1)                                     SROW0090
60045 FORMAT(24H INITIAL CRACK POSITION=,F8.3,25H    FINAL CRACK POSITIOSROW0091
    @N=,F8.3,42H   (+180 DEGREES FOR CRACK NO. 2 POSITION))             SROW0092
 50   WRITE(KW,6006) E,GNU                                              SROW0093
 6006 FORMAT(21H0MATERIAL PARAMETERS:,/,20H YOUNGS MODULUS (E)=,E12.5,/,SROW0094
    @16H POISSONS RATIO=,F8.3)                                          SROW0095
      SMU=E/(2.0*(1.0+GNU))                                             SROW0096
      ETA =(3.0-GNU)/(1.0+GNU)                                          SROW0097
      C(2,1)=GNU                                                        SROW0098
      C(3,3)=(1.0-GNU)/2.0                                              SROW0099
      S(2,1)=-GNU                                                       SROW0100
      S(3,3)=(1.0+GNU)*2.0                                              SROW0101
      GNU=E/(1.0-GNU*GNU)                                               SROW0102
      DO 60 I=1,3                                                       SROW0103
      DO 60 J=1,I                                                       SROW0104
      S(I,J)=S(I,J)/E                                                   SROW0105
      S(J,I)=S(I,J)                                                     SROW0106
      C(I,J)=C(I,J)*GNU                                                 SROW0107
 60   C(J,I)=C(I,J)                                                     SROW0108
```

```
C  PRINT OUT PROGRAM STATISTICS TO DATE:                               SROW0109
      IF(KT1 .EQ. KW ) GO TO 65                                        SROW0110
      WRITE(KW,6007) WIDTH,SMU,ETA                                     SROW0111
 6007 FORMAT(20H0PROGRAM STATISTICS:,/,13H PLATE WIDTH=,E12.5,/,5H SMU=,SROW0112
     @E12.5,/,5H ETA=,E12.5,//,9H S MATRIX,/)                          SROW0113
      WRITE(KW,6008) ((S(I,J),J=1,3),I=1,3)                            SROW0114
 6008 FORMAT(1H ,3E12.5)                                               SROW0115
      WRITE(KW,6009)                                                   SROW0116
 6009 FORMAT(10H0C MATRIX:)                                            SROW0117
      WRITE(KW,6008) ((C(I,J),J=1,3),I=1,3)                            SROW0118
C  CONSTRUCT SINGLE BOLT LINE STRUCTURE:                               SROW0119
 65   PRNTSV=KT1                                                       SROW0120
      KT1=KT2                                                          SROW0121
      LENGTH=LENGTH-CLSPC                                              SROW0122
      CALL SBL(THK,RI,S,BFORCE,NHOLES,IDMGD,CLSPC,LENGTH,WIDTH,NELW,   SROW0123
     @SCALE,NSZSS,RSS,ISS,NSZRNG,RRNG,IRNG,C)                          SROW0124
      DO 260 I=1,2                                                     SROW0125
      DO 260 J=1,13                                                    SROW0126
 260  SCALE(I,J)=SCALE(I,J)*BFORCE(IDMGD)                              SROW0127
      KT1=PRNTSV                                                       SROW0128
      DO 180 I=1,3                                                     SROW0129
 180  ISZBL(I)=ISZSS(I)                                                SROW0130
      DO 190 I=1,6                                                     SROW0131
 190  IBGBL(I)=IBEGIN(I)                                               SROW0132
C                                                                      SROW0133
C                                                                      SROW0134
C  CHESIRE CAT REMAINS                                                 SROW0135
C  SET UP CRACK PROBLEM:                                               SROW0136
      NET=2                                                            SROW0137
      NDT=96+NCRK*2                                                    SROW0138
      NCON=146+NCRK*2                                                  SROW0139
      CALL SETUP(NSIZE,1,NCON,REAL,INTGR)                              SROW0140
C  ELEMENT NO. 1 IS CHESIRE CAT                                        SROW0141
      IPNTR=IMASTR+NET                                                 SROW0142
      INTGR(IMASTR)=IPNTR                                              SROW0143
      DO 200 I=1,48                                                    SROW0144
```

```
      INTGR(IPNTR)=I
 200  IPNTR=IPNTR+1
C  ELEMENT NO. 2 IS THE CRACKED RING
      JLOC=IPOS(1)
      INTGR(IMASTR+1)=IPNTR
 205  IPNTR=INTGR(IMASTR+1)
      DO 206 I=49,NDT
      INTGR(IPNTR)=I
 206  IPNTR=IPNTR+1
      J=(JLOC+4)*2-1
      IF(JLOC .GE. 21) J=(JLOC-20)*2-1
      DO 210 I=J,48
      INTGR(IPNTR)=I
 210  IPNTR=IPNTR+1
      J=J-1
      IF(JLOC .EQ. 21) GO TO 225
      DO 220 I=1,J
      INTGR(IPNTR)=I
 220  IPNTR=IPNTR+1
 225  CONTINUE
      IF(KT1 .EQ. KW ) GO TO 230
      J=IMASTR+1
      WRITE(KW,6013) (INTGR(I),I=IMASTR,J)
 6013 FORMAT(41H0MASTER ASSEMBLY LIST FOR CRACK PROBLEM :,/,10H POINTERS
     @:,/,32H ELEMENT NO. 1 ( CHESIRE CAT ) =,I5,/,33H ELEMENT NO. 2 ( C
     @RACKED RING ) =,I5,/)
      J=J+1
      IPNTR=J+47
      WRITE(KW,6014) (INTGR(I),I=J,IPNTR)
 6014 FORMAT(38H ELEMENT NO. 1 (CHESIRE CAT) D.O.F.S: ,16I5,/,37X,16I5,/
     @,37X,16I5)
      IPNTR=IPNTR+1
      WRITE(KW,6015) (INTGR(I),I=IPNTR,LMASTR)
 6015 FORMAT(40H0ELEMENT NO. 2 ( CRACKED RING ) D.O.F.S:,16I5,/,37X,16I5
     @,/,37X,16I5,/,37X,16I5,/,37X,16I5,/,37X,16I5,/,37X,16I5)
 230  CALL ORK(NSIZE,REAL,INTGR)
```

```
      DO 240 I=1,3                                                      SROW0181
  240 ISZSS(I)=ISZBL(I)                                                 SROW0182
      DO 250 I=1,6                                                      SROW0183
  250 IBGSS(I)=IBGBL(I)                                                 SROW0184
      CALL ASMSUB(1,RSS,ISS,REAL,INTGR)                                 SROW0185
      THTCRK=DTHETA*(JLOC-1)                                            SROW0186
      PRNTSV=KT1                                                        SROW0187
      KT1=KT3                                                           SROW0188
      INDCTR=0                                                          SROW0189
      CALL RING(RI,THK,THTCRK,NCRK,A(1),A(2),INDCTR,S,C,NSZRNG,RRNG,IRNGSROW0190
     @)                                                                 SROW0191
      KT1=PRNTSV                                                        SROW0192
      CALL ASMSUB(2,RRNG,IRNG,REAL,INTGR)                               SROW0193
C   APPLY REMAINING BEARING LOAD:                                       SROW0194
      IF(JLOC .GT. 13) GO TO 290                                        SROW0195
      J=JLOC+1                                                          SROW0196
      IF(JLOC .EQ. 13) GO TO  275                                       SROW0197
      IDOF=IQ-47+NDT                                                    SROW0198
      DO 270 I=J,13                                                     SROW0199
      REAL(IDOF-1)=SCALE(1,I)                                           SROW0200
      REAL(IDOF)=SCALE(2,I)                                             SROW0201
  270 IDOF=IDOF+2                                                       SROW0202
  275 IDOF=NDT-(JLOC-1)*2+IQ-1                                          SROW0203
      J=J-1                                                             SROW0204
      IF(JLOC .EQ. 13) J=13                                             SROW0205
      DO 280 I=1,J                                                      SROW0206
      REAL(IDOF-1)=SCALE(1,I)                                           SROW0207
      REAL(IDOF)=SCALE(2,I)                                             SROW0208
  280 IDOF=IDOF+2                                                       SROW0209
      IF(NCRK .EQ. 0) GO TO 310                                         SROW0210
      REAL(IQ-2+NDT)=REAL(IQ-2+NDT)/2.0                                 SROW0211
      REAL(IQ-1+NDT)=REAL(IQ-1+NDT)/2.0                                 SROW0212
      REAL(IQ-50+NDT)=REAL(IQ-2+NDT)                                    SROW0213
      REAL(IQ-49+NDT)=REAL(IQ-1+NDT)                                    SROW0214
      IF(NCRK .EQ. 1) GO TO 310                                         SROW0215
      IF(JLOC .NE. 1 .AND.  JLOC .NE. 13) GO TO 310                     SROW0216
```

```
      REAL(IQ-26+NDT)=REAL(IQ-26+NDT)/2.0                               SROW0217
      REAL(IQ-25+NDT)=REAL(IQ-25+NDT)/2.0                               SROW0218
      REAL(IQ-52+NDT)=REAL(IQ-26+NDT)                                   SROW0219
      REAL(IQ-51+NDT)=REAL(IQ-25+NDT)                                   SROW0220
      GO TO 310                                                         SROW0221
  290 IDOF=NDT-25-(JLOC-13)*2 +IQ                                       SROW0222
      DO 300 I=1,13                                                     SROW0223
      REAL(IDOF-1)=SCALE(1,I)                                           SROW0224
      REAL(IDOF)=SCALE(2,I)                                             SROW0225
  300 IDOF=IDOF+2                                                       SROW0226
      IF(NCRK .NE. 2) GO TO 310                                         SROW0227
      REAL(IQ-26+NDT)=REAL(IQ-26+NDT)/2.0                               SROW0228
      REAL(IQ-25+NDT)=REAL(IQ-25+NDT)/2.0                               SROW0229
      REAL(IQ-52+NDT)=REAL(IQ-26+NDT)                                   SROW0230
      REAL(IQ-51+NDT)=REAL(IQ-25+NDT)                                   SROW0231
C  OBTAIN SOLUTION:                                                     SROW0232
  310 I=1                                                               SROW0233
      CALL FACT(I,REAL,INTGR)                                           SROW0234
      CALL SIMULQ(GNU,REAL,INTGR)                                       SROW0235
C  OBTAIN CRACKED RING INTERIOR DISPLACEMENTS:                          SROW0236
      CALL QBACK(2,RRNG,IRNG,REAL,INTGR)                                SROW0237
      IF(NCRK .EQ. 0) GO TO 360                                         SROW0238
      WRITE(KW,60145)                                                   SROW0239
60145 FORMAT(1H0)                                                       SROW0240
      DO 320 I=1,6                                                      SROW0241
      ISAVE2(I)=IBEGIN(I)                                               SROW0242
  320 IBEGIN(I)=IRGSS(I)                                                SROW0243
      THTCRK=THTCRK*180.0/PI                                            SROW0244
      DO 350 I=1,NCRK                                                   SROW0245
      CALL XTRACT(I+18,18,ELQ,RRNG,IRNG)                                SROW0246
      DO 330 J=1,2                                                      SROW0247
      RK(J)=0.0                                                         SROW0248
      DO 330 K=1,18                                                     SROW0249
  330 RK(J)=RK(J)+BCRK(I,J,K)*ELQ(K)                                    SROW0250
      DO 340 J=1,2                                                      SROW0251
  340 RK(J)=RK(J)*SQRTPI                                                SROW0252
```

```
      RK(2)=ABS(RK(2))                                                  SROW0253
      WRITE(KW,6016) I,THTCRK,(RK(J),J=1,2)                             SROW0254
 6016 FORMAT(11H CRACK NO. ,I2,9H   ANGLE=,F8.3,8H     KI=,E12.5,9H     SROW0255
     @KII=,E12.5)                                                       SROW0256
 350  THTCRK=THTCRK+180.0                                               SROW0257
C  INCREMENT CRACK POSITION:                                            SROW0258
 360  JLOC=JLOC+1                                                       SROW0259
      DO 370 I=1,6                                                      SROW0260
 370  IBEGIN(I)=ISAVE2(I)                                               SROW0261
      IF(JLOC .LE. IPOS(2)) GO TO 205                                   SROW0262
      STOP                                                              SROW0263
      END                                                               SROW0264
```

```
      SUBROUTINE SBL(THK,RI,S,BFORCE,NHOLES,IDMGD,CLSPC,LENGTH,WIDTH,   SBL 0000
     @NELW,SCALE,NSIZE,RSS,ISS,NSZHL,RHOLE,IHOLE,C)                     SBL 0001
C***********************************************************************SBL 0002
C***********************************************************************SBL 0003
C SUBROUTINE SBL (SINGLE BOLT LINE) CREATES A FINITE ELEMENT MODEL OF   SBL 0004
C A ROW OF FASTENER HOLES ALONG THE TOP EDGE OF A PLATE. ONE HOLE MUST  SBL 0005
C CONTAIN AT LEAST ONE CRACK.                                           SBL 0006
C***********************************************************************SBL 0007
C COPYRIGHT (C) 1975 MASSACHUSETTS INSTITUTE OF TECHNOLOGY              SBL 0008
C AEROELASTIC AND STRUCTURES RESEARCH LABORATORY                        SBL 0009
C***********************************************************************SBL 0010
C FINITE ELEMENT APPLICATIONS TO USAF STRUCTURAL INTEGRITY PROBLEMS     SBL 0011
      DIMENSION RSS(1),ISS(1),RHOLE(2097),IHOLE(2097),S(3,3),NODE(8),   SBL 0012
     @BFORCE(1),SCALE(2,13),COORD(12),B(6,3,13),C(3,3),ISAVE1(2),ISAVE2(SBL 0013
     @6),ISAVE3(6),ISZ(2)                                               SBL 0014
      REAL LENGTH                                                       SBL 0015
      INTEGER CNODE,CNSTRN (48)                                         SBL 0016
      COMMON/IO/KR,KW,KP,KT1,KT2,KT3                                    SBL 0017
      COMMON/SIZE/NET,NDT                                               SBL 0018
      COMMON/BEGIN/IBEGIN(6)                                            SBL 0019
      COMMON/END/IEND(6)                                                SBL 0020
      COMMON/SIZESS/NETSS,NDTSS,NID                                     SBL 0021
      COMMON/BEGSS/IBGSS(6)                                             SBL 0022
      EQUIVALENCE (NET,ISZ(1))                                          SBL 0023
      DATA PI/3.141593/                                                 SBL 0024
      DO 5 I=1,12                                                       SBL 0025
 5    COORD(I)=0.0                                                      SBL 0026
      NDW=2*NHOLES+1                                                    SBL 0027
      NET=NHOLES+1                                                      SBL 0028
      NDT=(3*NDW+(NHOLES+1)*24)*2                                       SBL 0029
      WIDTH=CLSPC/8.0                                                   SBL 0030
      IF(RI .GT. WIDTH) GO TO 170                                       SBL 0031
      WIDTH=CLSPC/12.0                                                  SBL 0032
      IF(RI .LT. WIDTH) GO TO 180                                       SBL 0033
      COORD(1)=CLSPC                                                    SBL 0034
      COORD(4)=CLSPC                                                    SBL 0035
```

```
      COORD(5)=CLSPC
      COORD(8)=CLSPC
      WIDTH=NHOLES*CLSPC
      NELW=2*NHOLES
      NCON=2*NHOLES+48-NDW+1
      LMASTR=NHOLES*65+4*NDW+1
      NIDSS=NDT-48
      IF( KT1 .EQ. KW ) GO TO 10
      WRITE(KW,6000) THK,RI,NHOLES,IDMGD,CLSPC,(BFORCE(I),I=1,NHOLES)
 6000 FORMAT(1H1,61X,9HENTRY SBL,///,23H SUBROUTINE INPUT DATA:,//,17H P
     @LATE THICKNESS=,E12.5,/,21H BEARING HOLE RADIUS=,E12.5,/,23H TOTAL
     @ NUMBER OF HOLES=,I5,/,36H I.D. OF DAMAGED HOLE (FROM L.H.S.)=,I5,
     @/,21H CENTER LINE SPACING=,E12.5,/,20H BEARING FORCE(LBS):,12E10.3
     @)
      WRITE(KW,6001) WIDTH,NELW,(COORD(I),I=1,12)
 6001 FORMAT(23H0SUBROUTINE STATISTICS:,/,24H CALCULATED PLATE WIDTH=,E1
     @2.5,/,46H NUMBER OF QUADRILATERALS NEEDED ACROSS WIDTH=,I5,/,20H H
     @OLE ELEMENT COORD:,12F8.3)
 10   CALL SETUP(NSIZE,NCON,LMASTR,RSS,ISS)
      IMASTR=IBEGIN(4)
      IPNTR=IMASTR+NET
      CNODE=NHOLES*26
      DO 40 N=1,NHOLES
      NM1=N-1
      ISS(IMASTR+NM1)=IPNTR
      NODER=CNODE-1
      NODEL=CNODE+1
      NODE(1)=NODER+2*NDW
      NODE(2)=NODER
      NODE(3)=NODER+NDW
      NODE(4)=CNODE+NDW
      NODE(5)=NODEL+NDW
      NODE(6)=NODEL
      NODE(7)=NODEL+2*NDW
      NODE(8)=CNODE+2*NDW
      DO 20 I=1,8
```

```
      IDOF=NODE(I)*2
      ISS(IPNTR)=IDOF-1
      ISS(IPNTR+1)=IDOF
20    IPNTR=IPNTR+2
      NODEL=NM1*48+1
      NODER=NODEL+47
      DO 30 I=NODEL,NODER
      ISS(IPNTR)=I
30    IPNTR=IPNTR+1
40    CNODE=CNODE-2
      IPNTR=ISS(IMASTR+IDMGD-1)+16
      NODER=IPNTR+47
      NODEL=NDT-47
      J=1
      DO 50 I=IPNTR,NODER
      CNSTRN (J)=ISS(I)
      ISS(I)=NODEL
      J=J+1
50    NODEL=NODEL+1
      NMBRCN=1
      DO 51 I=1,NDW
      ISS(NMBRCN)=CNSTRN (I*2)
51    NMBRCN=NMBRCN+1
      ISS(NMBRCN)=CNSTRN ((NELW/2+1)*2-1)
      IPNTR=ISS(IMASTR+NHOLES-1)+64
      ISS(IMASTR+NHOLES)=IPNTR
      NODEL=2*NDW
      DO 52 I=1,NODEL
      ISS(IPNTR)=CNSTRN (I)
52    IPNTR=IPNTR+1
      NODEL=NHOLES*48+4*NDW+1
      NODER=NODEL+2*NELW+1
      DO 53 I=NODEL,NODER
      ISS(IPNTR)=I
53    IPNTR=IPNTR+1
      IF( KT1 .EQ. KW ) GO TO 70
```

```
      IMASTR=IBEGIN(4)                                                  SBL 0108
      LMASTR=IMASTR+NET-1                                               SBL 0109
      WRITE(KW,6002) (ISS(I),I=IMASTR,LMASTR)                           SBL 0110
 6002 FORMAT(22H0MASTER ASSEMBLY LIST:,/,10H POINTERS:,20I5)            SBL 0111
      IMASTR=LMASTR+1                                                   SBL 0112
      LMASTR=IMASTR+63                                                  SBL 0113
      DO 60 N=1,NHOLES                                                  SBL 0114
      WRITE(KW,6003) N,(ISS(I),I=IMASTR,LMASTR)                         SBL 0115
 6003 FORMAT(17H0HOLE ELEMENT NO.,I3,10H  D.O.F.S:,/,15X,9HBOUNDARY:,16ISBL 0116
     @5,/,15X,15HHOLE INTERIOR: ,16I5,/,30X,16I5,/,30X,16I5)            SBL 0117
      IMASTR=LMASTR+1                                                   SBL 0118
 60   LMASTR=IMASTR+63                                                  SBL 0119
      LMASTR=IEND(4)                                                    SBL 0120
      WRITE(KW,60031)                                                   SBL 0121
60031 FORMAT(21H0LUG ELEMENT D.O.F.S:)                                  SBL 0122
      WRITE(KW,60032) (RSS(I),I=IMASTR,LMASTR)                          SBL 0123
60032 FORMAT(1H ,20I5)                                                  SBL 0124
 70   CALL ORK(NSIZE,RSS,ISS)                                           SBL 0125
      NCON=KT1                                                          SBL 0126
      KT1=KW                                                            SBL 0127
      IF(NHOLES .EQ. 1) GO TO 85                                        SBL 0128
      CALL HOLEL(COORD,THK,S,RI,RHOLE,IHOLE,B)                          SBL 0129
      DO 80 N=1,NHOLES                                                  SBL 0130
      IF( N .EQ. IDMGD) GO TO 80                                        SBL 0131
      CALL ASMSUB(N,RHOLE,IHOLE,RSS,ISS)                                SBL 0132
 80   CONTINUE                                                          SBL 0133
 85   RO=RI*((1.0+PI/12.0)**4)                                          SBL 0134
      CALL HOLEL(COORD,THK,S,RO,RHOLE,IHOLE,B)                          SBL 0135
      KT1=NCON                                                          SBL 0136
      CALL ASMSUB(IDMGD,RHOLE,IHOLE,RSS,ISS)                            SBL 0137
      DO 86 I=1,2                                                       SBL 0138
 86   ISAVE1(I)=ISZ(I)                                                  SBL 0139
      DO 87 I=1,6                                                       SBL 0140
      ISAVE2(I)=IBEGIN(I)                                               SBL 0141
 87   ISAVE3(I)=IEND(I)                                                 SBL 0142
      CNODE=KT1                                                         SBL 0143
```

```
      KT1=KT2                                                           SBL 0144
      CALL LUG(WIDTH,LENGTH,NELW,THK,THK,C,NSZHL,RHOLE,IHOLE)          SBL 0145
      KT1=CNODE                                                         SBL 0146
      DO 88 I=1,2                                                       SBL 0147
88    ISZ(I)=ISAVE1(I)                                                  SBL 0148
      DO 89 I=1,6                                                       SBL 0149
      IBEGIN(I)=ISAVE2(I)                                               SBL 0150
89    IEND(I)=ISAVE3(I)                                                 SBL 0151
      CALL ASMSUB(NHOLES+1,RHOLE,IHOLE,RSS,ISS)                         SBL 0152
      IMASTR=IBEGIN(5)-1                                                SBL 0153
      CNODE=NHOLES*52                                                   SBL 0154
      NCON=NMBRCN+1                                                     SBL 0155
      DO 100 N=1,NHOLES                                                 SBL 0156
      ISS(NCON)=CNODE                                                   SBL 0157
      ISS(NCON+1)=CNODE-1                                               SBL 0158
      RSS(IMASTR+ISS(NCON))=0.0                                         SBL 0159
      RSS(IMASTR+ISS(NCON+1))=0.0                                       SBL 0160
      NCON=NCON+2                                                       SBL 0161
100   CNODE=CNODE-4                                                     SBL 0162
      NODEL=2*NDW+1                                                     SBL 0163
      DO 105 I=NODEL,48                                                 SBL 0164
      ISS(NCON)=CNSTRN (I)                                              SBL 0165
105   NCON=NCON+1                                                       SBL 0166
      NCON=NCON-1                                                       SBL 0167
      DO 106 I=1,NCON                                                   SBL 0168
106   RSS(IMASTR+ISS(I))=0.0                                            SBL 0169
      DTHETA=PI/24.0                                                    SBL 0170
      DTHT=PI/12.0                                                      SBL 0171
      PO=2.0/(RI*THK*PI)                                                SBL 0172
      THETA=0.0                                                         SBL 0173
      DO 120 I=1,7                                                      SBL 0174
      SS1=SIN(THETA-DTHETA)                                             SBL 0175
      SS2=SIN(THETA+DTHETA)                                             SBL 0176
      IF( I .EQ. 1 ) SS1=0.0                                            SBL 0177
      IF( I .EQ. 13 ) SS2=0.0                                           SBL 0178
      PNODE=PO*THK*DTHETA*(SS2+SS1)*RI                                  SBL 0179
```

```
      IF( KT1 .EQ. KW ) GO TO 110                                       SBL 0180
      WRITE(KW,6004) I,PNODE                                            SBL 0181
 6004 FORMAT(41H0CONSISTENT RR NODAL FORCE; GENERAL NODE ,I3,28H  SCALEDSBL 0182
     @ P (XBEARING FORCE)=,E12.5)                                       SBL 0183
 110  SCALE(2,I)=PNODE*SIN(THETA)                                       SBL 0184
      SCALE(1,I)=PNODE*COS(THETA)                                       SBL 0185
      IF (KT1 .EQ. KW ) GO TO 120                                       SBL 0186
      WRITE(KW,6005) I,(SCALE(J,I),J=1,2)                               SBL 0187
 6005 FORMAT(21H0SCALE FACTORS; NODE ,I3,9H X SCALE=,E12.5,11H   Y SCALESBL 0188
     @=,E12.5)                                                          SBL 0189
 120  THETA=THETA+DTHT                                                  SBL 0190
      DO 125 I=8,13                                                     SBL 0191
      IMASTR=14-I                                                       SBL 0192
      DO 125 J=1,2                                                      SBL 0193
 125  SCALE(J,I)=SCALE(J,IMASTR)                                        SBL 0194
      DO 126 I=8,13                                                     SBL 0195
 126  SCALE(1,I)=-SCALE(1,I)                                            SBL 0196
      SCALE(1,7)=0.0                                                    SBL 0197
      IF (NHOLES .EQ. 1) GO TO 145                                      SBL 0198
      NODEL=7                                                           SBL 0199
      IMASTR=IBEGIN(5)-1                                                SBL 0200
      DO 140 N=1,NHOLES                                                 SBL 0201
      IF( N .EQ. IDMGD ) GO TO 140                                      SBL 0202
      DO 130 I=1,13                                                     SBL 0203
      DO 130 J=1,2                                                      SBL 0204
      RSS(IMASTR+NODEL)=SCALE(J,I)*BFORCE(N)                            SBL 0205
 130  NODEL=NODEL+1                                                     SBL 0206
 140  NODEL=N*48+7                                                      SBL 0207
 145  CALL BCON(RSS,ISS)                                                SBL 0208
      I=1                                                               SBL 0209
      CALL STACON(I,NIDSS,RSS,ISS)                                      SBL 0210
      DO 150 I=1,6                                                      SBL 0211
 150  IBGSS(I)=IBEGIN(I)                                                SBL 0212
      NETSS=NET                                                         SBL 0213
      NDTSS=NDT                                                         SBL 0214
      NID=NIDSS                                                         SBL 0215
```

```
      IF (KT1 .EQ. KW) GO TO 160                                        SBL 0216
      WRITE(KW,6006)                                                    SBL 0217
 6006 FORMAT(1H0,61X,8HEXIT SBL)                                        SBL 0218
 160  RETURN                                                            SBL 0219
 170  WRITE(KW,6007) RI,CLSPC                                           SBL 0220
 6007 FORMAT(56H0*****PROGRAM INTERUPT INITIATED BY SUBROUTINE SBL *****SBL 0221
     @,//,27H USER SPECIFIED DIMENSIONS:,/,10X,13H HOLE RADIUS=,E12.5,/,SBL 0222
     @10X,30H CENTER LINE SPACING OF HOLES=,E12.5,//,87H SUCH DIMENSIONSSBL 0223
     @ WILL CAUSE UNACCEPTABLE PROBLEMS WITH HOLE ELEMENT AND MUST BE ALSBL 0224
     @TERED,//,21H RECOMMENDED CHANGES:,//)                             SBL 0225
      CLSPC=8.0*RI                                                      SBL 0226
      WRITE(KW,6008) WIDTH,CLSPC                                        SBL 0227
 6008 FORMAT(33H LET RI BE LESS THAN OR EQUAL TO ,E12.5.56H OR LET CENTESBL 0228
     @R LINE SPACING BE GREATER THAN OR EQUAL TO ,E12.5)                SBL 0229
      GO TO 190                                                         SBL 0230
 180  WRITE(KW,6007) RI,CLSPC                                           SBL 0231
      CLSPC=12.0*RI                                                     SBL 0232
      WRITE(KW,6009) WIDTH,CLSPC                                        SBL 0233
 6009 FORMAT(36H LET RI BE GREATER THAN OR EQUAL TO ,E12.5,53H OR LET CESBL 0234
     @NTER LINE SPACING BE LESS THAN OR EQUAL TO ,E12.5)                SBL 0235
 190  WRITE(KW,6010)                                                    SBL 0236
 6010 FORMAT(51H0***** EXECUTION TERMINATED IN SUBROUTINE SBL *****)    SBL 0237
      STOP                                                              SBL 0238
      END                                                               SBL 0239
```

```
C  TEST MAIN FOR DOUBLE ROW OF BOLT HOLES (DROW)                        DROW0001
C***********************************************************************DROW0002
C COPYRIGHT (C) 1975 MASSACHUSETTS INSTITUTE OF TECHNOLOGY              DROW0003
C AEROELASTIC AND STRUCTURES RESEARCH LABORATORY                        DROW0004
C***********************************************************************DROW0005
C FINITE ELEMENT APPLICATIONS TO USAF STRUCTURAL INTEGRITY PROBLEMS     DROW0006
C........INPUT DATA FOR PROBLEM #6 - DOUBLE ROW OF BOLT HOLES...........DROW0007
C SET         VARIABLES IN SET                     FORMAT FOR EACH CARD DROW0008
C  1          NHOLES,CLSPC,RI,IROW,IDMGD,LENGTH,THK (I5,2E10.3,2I5,2E10.3)DROW0009
C  2          BFORCE(I), FOR I=1,2,3...NHOLES  (FOR ROW 1)        (8E10.3)DROW0010
C  3          BFORCE(I), FOR I=1,2,3...NHOLES  (FOR ROW 2)        (8E10.3)DROW0011
C  4          A(1),A(2),IPOS(1),IPOS(2)                       (2E10.3,2I5)DROW0012
C  5          E,GNU                                               (2E10.3)DROW0013
C  6          KT1,KT2,KT3                                            (3I5)DROW0014
C =====DEFINITIONS OF INPUT VARIABLES===================================DROW0015
C NHOLES = NO. OF HOLES;  CLSPC = CENTER LINE SPACING OF HOLES          DROW0016
C RI = RADIUS OF HOLE;  IROW = ROW CONTAINING DAMAGED HOLE (FROM TOP)   DROW0017
C IDMGD = POSITION NO. OF DAMAGED HOLE FROM L.H.S.                      DROW0018
C LENGTH = LENGTH OF PLATE;  THK = THICKNESS OF PLATE                   DROW0019
C BFORCE(I) = MULTIPLIER FOR LOAD IN HOLE I;  A(1) = LENGTH OF CRACK ONEDROW0020
C A(2) = LENGTH OF CRACK NO. TWO;  IPOS(1) = INITIAL POSITION OF CRACK 1DROW0021
C IPOS(2) = FINAL POSITION OF CRACK 1; E = YOUNGS MODULUS;              DROW0022
C GNU = POISSONS RATIO;  KT1 = PRINT CONTROL FOR FEABL OPTIONAL PRINT;  DROW0023
C KT2 = PRINT CONTROL FOR OPTIONAL DBL PRINTING                         DROW0024
C KT3 = PRINT CONTROL FOR OPTIONAL RING PRINTING                        DROW0025
C***********************************************************************DROW0026
      DIMENSION RSS(30000),ISS(30000),REAL(8000),INTGR(8000),RRNG(12000)DROW0027
     @,IRNG(12000),A(2),IPOS(2),BFORCE(20),S(3,3),C(3,3),SCALE(2,13),IBEDROW0028
     @GIN(6),IEND(6),ISZSS(3),ISZBL(3),IBGBL(6),ISAVE1(2),ISAVE2(6),ISAVDROW0029
     @E3(6),ISZ(2),ELQ(18),RK(2)                                        DROW0030
      INTEGER PRNTSV                                                    DROW0031
      REAL LENGTH                                                       DROW0032
      COMMON/IO/KR,KW,KP,KT1,KT2,KT3                                    DROW0033
      COMMON/SIZE/NET,NDT                                               DROW0034
      COMMON/BEGIN/ICON,IKOUNT,ILNZ,IMASTR,IQ,IK                        DROW0035
      COMMON/END/LCON,LKOUNT,LLNZ,LMASTR,LQ,LK                          DROW0036
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      COMMON/SIZESS/NETSS,NDTSS,NIDSS                                   DROW0037
      COMMON/BEGSS/IBGSS(6)                                             DROW0038
      COMMON/MTLPRM/SMU,ETA                                             DROW0039
      COMMON/KI/BCRK(2,2,18)                                            DROW0040
      EQUIVALENCE (RSS(1),ISS(1)),(REAL(1),INTGR(1)),(RRNG(1),IRNG(1)), DROW0041
     @(ISZ(1),NET),(IBEGIN(1),ICON),(IEND(1),LCON),(ISZSS(1),NETSS)     DROW0042
      DATA PI/3.141593/,C/1.0,3*0.0,1.0,4*0.0/,S/1.0,3*0.0,1.0,4*0.0/   DROW0043
      DTHETA=PI/12.0                                                    DROW0044
      SQRTPI=SQRT(PI)                                                   DROW0045
      DATA NSZSS/30000/,NSIZE/ 8000/,NSZRNG/12000/                      DROW0046
      KR=5                                                              DROW0047
      KW=6                                                              DROW0048
C  INPUT DATA:                                                          DROW0049
      READ (KR,5000) NHOLES,CLSPC,RI,IROW,IDMGD,LENGTH,THK              DROW0050
 5000 FORMAT(I5,2E10.3,2I5,2E10.3)                                      DROW0051
      DO 10 I=1,2                                                       DROW0052
      J1=(I-1)*NHOLES+1                                                 DROW0053
      J2=J1+NHOLES-1                                                    DROW0054
 10   READ(KR,5001) (BFORCE(J),J=J1,J2)                                 DROW0055
 5001 FORMAT(8E10.3)                                                    DROW0056
      NH2=2*NHOLES                                                      DROW0057
      READ(KR,5002) A(1),A(2),IPOS(1),IPOS(2)                           DROW0058
 5002 FORMAT(2E10.3,2I5)                                                DROW0059
      READ(KR,5002) E,GNU                                               DROW0060
      READ(KR,5004) KT1,KT2,KT3                                         DROW0061
 5004 FORMAT(3I5)                                                       DROW0062
      WRITE(KW,6000) NHOLES,CLSPC,RI,IROW,IDMGD                         DROW0063
 6000 FORMAT(1H1,56X,16HDOUBLE BOLT LINE,//,59X,13HPROBLEM NO. 6,///,60XDROW0064
     @,10HINPUT DATA,/,25H NUMBER OF HOLES PER ROW=,I3,/,30H CENTER LINEDROW0065
     @ SPACING OF HOLES=,E12.5,/,21H BEARING HOLE RADIUS=,E12.5,/,20H DADROW0066
     @MAGED HOLE IN ROW,I2,3H IS,I3,12H FROM L.H.S.)                    DROW0067
      WIDTH=3.*CLSPC                                                    DROW0068
      IF(LENGTH .GE. WIDTH) GO TO 20                                    DROW0069
      WRITE(KW,6001) WIDTH                                              DROW0070
 6001 FORMAT(29H0***** PROGRAM INTERUPT *****,/,109H USER SPECIFIED PLATDROW0071
     @E DIMENSION LENGTH IS LESS THAN ACCEPTABLE MINIMUM.   DIMENSION LEDROW0072
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     @NGTH WILL BE CHANGED TO ,E12.5/)                                  DROW0073
      LENGTH=WIDTH                                                      DROW0074
 20   WIDTH=NHOLES*CLSPC+.5*CLSPC                                       DROW0075
      WRITE(KW,6002) LENGTH,WIDTH,THK                                   DROW0076
 6002 FORMAT(14H PLATE LENGTH=,E12.5,/,13H PLATE WIDTH=,E12.5,/,17H PLATDROW0077
     @E THICKNESS=,E12.5,/,41H BEARING LOADS :    HOLE       FORCE(LBS),DROW0078
     @/)                                                                DROW0079
      DO 32 NROW=1,2                                                    DROW0080
      DO 30 I=1,NHOLES                                                  DROW0081
      J=I+(NROW-1)*NHOLES                                               DROW0082
 30   WRITE(KW,6003) NROW,I,BFORCE(J)                                   DROW0083
 32   CONTINUE                                                          DROW0084
 6003 FORMAT(1H ,9X,4HROW=,I2,4X,I2,5X,E12.5)                           DROW0085
      NCRK=0                                                            DROW0086
      DO 40 I=1,2                                                       DROW0087
 40   IF( A(I) .GT. 0.0) NCRK=NCRK+1                                    DROW0088
      WRITE(KW,6004) NCRK                                               DROW0089
 6004 FORMAT(12H0CRACK DATA:,/,24H TOTAL NUMBER OF CRACKS=,I2)          DROW0090
      IF(NCRK .EQ. 0 ) GO TO 50                                         DROW0091
      WRITE(KW,6005) (I,A(I),I=1,NCRK)                                  DROW0092
 6005 FORMAT(11H CRACK NO. ,3X,13H CRACK LENGTH,//,5X,I5,4X,E12.5,/,5X,IDROW0093
     @5,4X,E12.5)                                                       DROW0094
      S(3,3)=(IPOS(1)-1)*15.0                                           DROW0095
      S(2,1)=(IPOS(2)-1)*15.0                                           DROW0096
      WRITE(KW,60045) S(3,3),S(2,1)                                     DROW0097
60045 FORMAT(24H INITIAL CRACK POSITION=,F8.3,25H    FINAL CRACK POSITIODROW0098
     @N=,F8.3,42H   (+180 DEGREES FOR CRACK NO. 2 POSITION))            DROW0099
 50   WRITE(KW,6006) E,GNU                                              DROW0100
 6006 FORMAT(21H0MATERIAL PARAMETERS:,/,20H YOUNGS MODULUS (E)=,E12.5,/,DROW0101
     @16H POISSONS RATIO=,F8.3)                                         DROW0102
      SMU=E/(2.0*(1.0+GNU))                                             DROW0103
      ETA =(3.0-GNU)/(1.0+GNU)                                          DROW0104
      C(2,1)=GNU                                                        DROW0105
      C(3,3)=(1.0-GNU)/2.0                                              DROW0106
      S(2,1)=-GNU                                                       DROW0107
      S(3,3)=(1.0+GNU)*2.0                                              DROW0108
```

```
      GNU=E/(1.0-GNU*GNU)                                               DROW0109
      DO 60 I=1,3                                                       DROW0110
      DO 60 J=1,I                                                       DROW0111
      S(I,J)=S(I,J)/E                                                   DROW0112
      S(J,I)=S(I,J)                                                     DROW0113
      C(I,J)=C(I,J)*GNU                                                 DROW0114
   60 C(J,I)=C(I,J)                                                     DROW0115
C  PRINT OUT PROGRAM STATISTICS TO DATE:                                DROW0116
      IF(KT1 .EQ. KW ) GO TO 65                                         DROW0117
      WRITE(KW,6007) WIDTH,SMU,ETA                                      DROW0118
 6007 FORMAT(20H0PROGRAM STATISTICS:,/,13H PLATE WIDTH=,E12.5,/,5H SMU=,DROW0119
     @E12.5,/,5H ETA=,E12.5,//,9H S MATRIX,/)                           DROW0120
      WRITE(KW,6008) ((S(I,J),J=1,3),I=1,3)                             DROW0121
 6008 FORMAT(1H ,3F12.5)                                                DROW0122
      WRITE(KW,6009)                                                    DROW0123
 6009 FORMAT(10H0C MATRIX:)                                             DROW0124
      WRITE(KW,6008) ((C(I,J),J=1,3),I=1,3)                             DROW0125
C  CONSTRUCT SINGLE BOLT LINE STRUCTURE:                                DROW0126
   65 PRNTSV=KT1                                                        DROW0127
      KT1=KT2                                                           DROW0128
      LENGTH=LENGTH-2.*CLSPC                                            DROW0129
      CALL DBL(THK,RI,S,BFORCE,NHOLES,IROW,IDMGD,CLSPC,LENGTH,WIDTH,NELWDROW0130
     @,SCALE,NSZSS,RSS,ISS,NSZRNG,RRNG,IRNG,C)                          DROW0131
      IDM=(IROW-1)*NHOLES+IDMGD                                         DROW0132
      DO 260 I=1,2                                                      DROW0133
      DO 260 J=1,13                                                     DROW0134
  260 SCALE(I,J)=SCALE(I,J)*BFORCE(IDM)                                 DROW0135
      KT1=PRNTSV                                                        DROW0136
      DO 180 I=1,3                                                      DROW0137
  180 ISZBL(I)=ISZSS(I)                                                 DROW0138
      DO 190 I=1,6                                                      DROW0139
  190 IBGBL(I)=IBEGIN(I)                                                DROW0140
C                                                                       DROW0141
C                                                                       DROW0142
C  CHESIRE CAT REMAINS                                                  DROW0143
C  SET UP CRACK PROBLEM:                                                DROW0144
```

```
      NET=2                                                             DROW0145
      NDT=96+NCRK*2                                                     DROW0146
      NCON=146+NCRK*2                                                   DROW0147
      CALL SETUP(NSIZE,1,NCON,REAL,INTGR)                               DROW0148
C  ELEMENT NO. 1 IS CHESIRE CAT                                         DROW0149
      IPNTR=IMASTR+NET                                                  DROW0150
      INTGR(IMASTR)=IPNTR                                               DROW0151
      DO 200 I=1,48                                                     DROW0152
      INTGR(IPNTR)=I                                                    DROW0153
  200 IPNTR=IPNTR+1                                                     DROW0154
C  ELEMENT NO. 2 IS THE CRACKED RING                                    DROW0155
      JLOC=IPOS(1)                                                      DROW0156
      INTGR(IMASTR+1)=IPNTR                                             DROW0157
  205 IPNTR=INTGR(IMASTR+1)                                             DROW0158
      DO 206 I=49,NDT                                                   DROW0159
      INTGR(IPNTR)=I                                                    DROW0160
  206 IPNTR=IPNTR+1                                                     DROW0161
      J=(JLOC+4)*2-1                                                    DROW0162
      IF(JLOC .GE. 21) J=(JLOC-20)*2-1                                  DROW0163
      DO 210 I=J,48                                                     DROW0164
      INTGR(IPNTR)=I                                                    DROW0165
  210 IPNTR=IPNTR+1                                                     DROW0166
      J=J-1                                                             DROW0167
      IF(JLOC .EQ. 21) GO TO 225                                        DROW0168
      DO 220 I=1,J                                                      DROW0169
      INTGR(IPNTR)=I                                                    DROW0170
  220 IPNTR=IPNTR+1                                                     DROW0171
  225 CONTINUE                                                          DROW0172
      IF(KT1 .EQ. KW ) GO TO 230                                        DROW0173
      J=IMASTR+1                                                        DROW0174
      WRITE(KW,6013) (INTGR(I),I=IMASTR,J)                              DROW0175
 6013 FORMAT(41H0MASTER ASSEMBLY LIST FOR CRACK PROBLEM :,/,10H POINTERSDROW0176
     @:,/,32H ELEMENT NO. 1 ( CHESIRE CAT ) =,I5,/,33H ELEMENT NO. 2 ( CDROW0177
     @RACKED RING ) =,I5,/)                                             DROW0178
      J=J+1                                                             DROW0179
      IPNTR=J+47                                                        DROW0180
```

```
      WRITE(KW,6014) (INTGR(I),I=J,IPNTR)                               DROW0181
 6014 FORMAT(38H ELEMENT NO. 1 (CHESIRE CAT) D.O.F.S: ,16I5,/,37X,16I5,/DROW0182
     @,37X,16I5)                                                        DROW0183
      IPNTR=IPNTR+1                                                     DROW0184
      WRITE(KW,6015) (INTGR(I),I=IPNTR,LMASTR)                          DROW0185
 6015 FORMAT(40H0ELEMENT NO. 2 ( CRACKED RING ) D.O.F.S:,16I5,/,37X,16I5DROW0186
     @,/,37X,16I5,/,37X,16I5,/,37X,16I5,/,37X,16I5,/,37X,16I5)          DROW0187
  230 CALL ORK(NSIZE,REAL,INTGR)                                        DROW0188
      DO 240 I=1,3                                                      DROW0189
  240 ISZSS(I)=ISZBL(I)                                                 DROW0190
      DO 250 I=1,6                                                      DROW0191
  250 IBGSS(I)=IBGBL(I)                                                 DROW0192
      CALL ASMSUB(1,RSS,ISS,REAL,INTGR)                                 DROW0193
      THTCRK=DTHETA*(JLOC-1)                                            DROW0194
      PRNTSV=KT1                                                        DROW0195
      KT1=KT3                                                           DROW0196
      INDCTR=0                                                          DROW0197
      CALL RING(RI,THK,THTCRK,NCRK,A(1),A(2),INDCTR,S,C,NSZRNG,RRNG,IRNGDROW0198
     @)                                                                 DROW0199
      KT1=PRNTSV                                                        DROW0200
      CALL ASMSUB(2,RRNG,IRNG,REAL,INTGR)                               DROW0201
C   APPLY REMAINING BEARING LOAD:                                       DROW0202
      IF(JLOC .GT. 13) GO TO 290                                        DROW0203
      J=JLOC+1                                                          DROW0204
      IF(JLOC .EQ. 13) GO TO  275                                       DROW0205
      IDOF=IQ-47+NDT                                                    DROW0206
      DO 270 I=J,13                                                     DROW0207
      REAL(IDOF-1)=SCALE(1,I)                                           DROW0208
      REAL(IDOF)=SCALE(2,I)                                             DROW0209
  270 IDOF=IDOF+2                                                       DROW0210
  275 IDOF=NDT-(JLOC-1)*2+IQ-1                                          DROW0211
      J=J-1                                                             DROW0212
      IF(JLOC .EQ. 13) J=13                                             DROW0213
      DO 280 I=1,J                                                      DROW0214
      REAL(IDOF-1)=SCALE(1,I)                                           DROW0215
      REAL(IDOF)=SCALE(2,I)                                             DROW0216
```

```
280   IDOF=IDOF+2                                                  DROW0217
      IF(NCRK .EQ. 0) GO TO 310                                    DROW0218
      REAL(IQ-2+NDT)=REAL(IQ-2+NDT)/2.0                            DROW0219
      REAL(IQ-1+NDT)=REAL(IQ-1+NDT)/2.0                            DROW0220
      REAL(IQ-50+NDT)=REAL(IQ-2+NDT)                               DROW0221
      REAL(IQ-49+NDT)=REAL(IQ-1+NDT)                               DROW0222
      IF(NCRK .EQ. 1) GO TO 310                                    DROW0223
      IF(JLOC .NE. 1 .AND.  JLOC .NE. 13) GO TO 310                DROW0224
      REAL(IQ-26+NDT)=REAL(IQ-26+NDT)/2.0                          DROW0225
      REAL(IQ-25+NDT)=REAL(IQ-25+NDT)/2.0                          DROW0226
      REAL(IQ-52+NDT)=REAL(IQ-26+NDT)                              DROW0227
      REAL(IQ-51+NDT)=REAL(IQ-25+NDT)                              DROW0228
      GO TO 310                                                    DROW0229
290   IDOF=NDT-25-(JLOC-13)*2 +IQ                                  DROW0230
      DO 300 I=1,13                                                DROW0231
      REAL(IDOF-1)=SCALE(1,I)                                      DROW0232
      REAL(IDOF)=SCALE(2,I)                                        DROW0233
300   IDOF=IDOF+2                                                  DROW0234
      IF(NCRK .NE. 2) GO TO 310                                    DROW0235
      REAL(IQ-26+NDT)=REAL(IQ-26+NDT)/2.0                          DROW0236
      REAL(IQ-25+NDT)=REAL(IQ-25+NDT)/2.0                          DROW0237
      REAL(IQ-52+NDT)=REAL(IQ-26+NDT)                              DROW0238
      REAL(IQ-51+NDT)=REAL(IQ-25+NDT)                              DROW0239
C  OBTAIN SOLUTION:                                                DROW0240
310   I=1                                                          DROW0241
      CALL FACT(I,REAL,INTGR)                                      DROW0242
      CALL SIMULQ(GNU,REAL,INTGR)                                  DROW0243
C  OBTAIN CRACKED RING INTERIOR DISPLACEMENTS:                     DROW0244
      CALL QBACK(2,RRNG,IRNG,REAL,INTGR)                           DROW0245
      IF(NCRK .EQ. 0) GO TO 360                                    DROW0246
      WRITE(KW,60145)                                              DROW0247
60145 FORMAT(1H0)                                                  DROW0248
      DO 320 I=1,6                                                 DROW0249
      ISAVE2(I)=IBEGIN(I)                                          DROW0250
320   IBEGIN(I)=IBGSS(I)                                           DROW0251
      THTCRK=THTCRK*180.0/PI                                       DROW0252
```

```
      DO 350 I=1,NCRK                                                   DROW0253
      CALL XTRACT(I+18,18,ELQ,RRNG,IRNG)                                DROW0254
      DO 330 J=1,2                                                      DROW0255
      RK(J)=0.0                                                         DROW0256
      DO 330 K=1,18                                                     DROW0257
 330  RK(J)=RK(J)+BCRK(I,J,K)*ELQ(K)                                    DROW0258
      DO 340 J=1,2                                                      DROW0259
 340  RK(J)=RK(J)*SQRTPI                                                DROW0260
      RK(2)=ABS(RK(2))                                                  DROW0261
      WRITE(KW,6016) I,THTCRK,(RK(J),J=1,2)                             DROW0262
 6016 FORMAT(11H CRACK NO. ,I2,9H   ANGLE=,F8.3,8H     KI=,E12.5,9H     DROW0263
     @KII=,E12.5)                                                       DROW0264
 350  THTCRK=THTCRK+180.0                                               DROW0265
C  INCREMENT CRACK POSITION:                                            DROW0266
 360  JLOC=JLOC+1                                                       DROW0267
      DO 370 I=1,6                                                      DROW0268
 370  IBEGIN(I)=ISAVE2(I)                                               DROW0269
      IF(JLOC .LE. IPOS(2)) GO TO 205                                   DROW0270
      STOP                                                              DROW0271
      END                                                               DROW0272
```

```
      SUBROUTINE DBL(THK,RI,S,BFORCE,NHOLES,IROW,IDMGD,CLSPC,LENGTH,WIDTDBL 0000
     @H,NELW,SCALE,NSIZE,RSS,ISS,NSZHL,RHOLE,IHOLE,C)                   DBL 0001
C***********************************************************************DBL 0002
C SUBROUTINE DBL (DOUBLE BOLT LINE) CREATES A FINITE ELEMENT MODEL OF   DBL 0003
C 2 ROWS OF FASTENER HOLES ALONG THE TOP EDGE OF A PLATE. ONE HOLE MUST DBL 0004
C CONTAIN AT LEAST ONE CRACK.                                           DBL 0005
C***********************************************************************DBL 0006
C COPYRIGHT (C) 1975 MASSACHUSETTS INSTITUTE OF TECHNOLOGY              DBL 0007
C AEROELASTIC AND STRUCTURES RESEARCH LABORATORY                        DBL 0008
C FINITE ELEMENT APPLICATIONS TO USAF STRUCTURAL INTEGRITY PROBLEMS     DBL 0009
C THIS DOUBLE BOLT LINE SUBROUTINE IS A MODIFICATION OF GEORGE STALKS   DBL 0010
C SUBROUTINE SBL WHICH IS FOR A SINGLE BOLT LINE                        DBL 0011
      DIMENSION RSS(1),ISS(1),RHOLE(2097),IHOLE(2097),S(3,3),NODE(8),   DBL 0012
     @BFORCE(1),SCALE(2,13),COORD(12),B(6,3,13),C(3,3),ISAVE1(2),ISAVE2(DBL 0013
     @6),ISAVE3(6),ISZ(2),XY(12), EF(8), ELK(36), BMAT(3,9)             DBL 0014
      REAL LENGTH                                                       DBL 0015
      INTEGER CNODE,CNSTRN (48)                                         DBL 0016
      COMMON/IO/KR,KW,KP,KT1,KT2,KT3                                    DBL 0017
      COMMON/SIZE/NET,NDT                                               DBL 0018
      COMMON/BEGIN/IBEGIN(6)                                            DBL 0019
      COMMON/END/IEND(6)                                                DBL 0020
      COMMON/SIZESS/NETSS,NDTSS,NID                                     DBL 0021
      COMMON/BEGSS/IBGSS(6)                                             DBL 0022
      EQUIVALENCE (NET,ISZ(1))                                          DBL 0023
      DATA PI/3.141593/                                                 DBL 0024
      DO 5 I=1,12                                                       DBL 0025
      XY(I)=0.                                                          DBL 0026
    5 COORD(I)=0.0                                                      DBL 0027
      NDW=2*NHOLES+2                                                    DBL 0028
      NET=2*NHOLES+5                                                    DBL 0029
      NDT=116*NHOLES+68                                                 DBL 0030
      WIDTH=CLSPC/8.0                                                   DBL 0031
      IF(RI .GT. WIDTH) GO TO 170                                       DBL 0032
      WIDTH=CLSPC/12.0                                                  DBL 0033
      IF(RI .LT. WIDTH) GO TO 180                                       DBL 0034
C COORDINATES FOR HOLE SUBSTRUCTURE                                     DBL 0035
```

```
      COORD(1)=CLSPC
      COORD(4)=CLSPC
      COORD(5)=CLSPC
      COORD(8)=CLSPC
C COORDINATES FOR QUAD4 ELEMENT
      WIDTH=.5*CLSPC
      XY(1)=WIDTH
      XY(4)=WIDTH
      XY(5)=WIDTH
      XY(8)=WIDTH
      WIDTH=NHOLES*CLSPC+WIDTH
      NELW=2*NHOLES+1
      NH2=2*NHOLES
      NCON=48+NH2
      LMASTR=2*65*NHOLES+9*4+4*NDW+1
      NIDSS=NDT-48
      IF( KT1 .EQ. KW ) GO TO 10
      WRITE(KW,6000) THK,RI,NH2,IDMGD,IROW,CLSPC,(BFORCE(I),I=1,NH2)
 6000 FORMAT(1H1,61X,9HENTRY DBL,///,23H SUBROUTINE INPUT DATA:,//,17H P
     @LATE THICKNESS=,E12.5,/,21H BEARING HOLE RADIUS=,E12.5,/,23H TOTAL
     @ NUMBER OF HOLES=,I5,/,36H I.D. OF DAMAGED HOLE (FROM L.H.S.)=,I5,
     @8H IN ROW=,I2,/,21H CENTER LINE SPACING=,E12.5,/,20H BEARING FORCE
     @(LBS):,12E10.3,/,1H ,8E10.3)
      WRITE(KW,6001) WIDTH,NELW,(COORD(I),I=1,12)
 6001 FORMAT(23H0SUBROUTINE STATISTICS:,/,24H CALCULATED PLATE WIDTH=,E1
     @2.5,/,46H NUMBER OF QUADRILATERALS NEEDED ACROSS WIDTH=,I5,/,20H H
     @OLE ELEMENT COORD:,12F8.3)
 10   CALL SETUP(NSIZE,NCON,LMASTR,RSS,ISS)
      IMASTR=IBEGIN(4)
      IPNTR=IMASTR+NET
      CNODE=50*NHOLES+1
      K1=2*NDW
      K2=NDW
      N1=1
      N2=NHOLES
      DO 42 NROW=1,2
```

```
      DO 40 N=N1,N2
C MASTER LIST FOR HOLE SUBSTRUCTURES
      NM1=N-1
      ISS(IMASTR+NM1)=IPNTR
      NODER=CNODE-1
      NODEL=CNODE+1
      NODE(1)=NODER+K1
      NODE(2)=NODER
      NODE(3)=NODER+K2
      NODE(4)=CNODE+K2
      NODE(5)=NODEL+K2
      NODE(6)=NODEL
      NODE(7)=NODEL+K1
      NODE(8)=CNODE+K1
      DO 20 I=1,8
      IDOF=NODE(I)*2
      ISS(IPNTR)=IDOF-1
      ISS(IPNTR+1)=IDOF
   20 IPNTR=IPNTR+2
      NODEL=NM1*48+1
      NODER=NODEL+47
      DO 30 I=NODEL,NODER
      ISS(IPNTR)=I
   30 IPNTR=IPNTR+1
   40 CNODE=CNODE-2
      CNODE=56*NHOLES+6
      K1=NDW
      K2=-NDW
      N1=N2+1
   42 N2=NH2
C MASTER LIST FOR QUAD4 ELEMENTS
      NM1=IMASTR+NH2-1
      DO 49 IEL=1,4
      ISS(NM1+IEL)=IPNTR
      GO TO (43,44,45,46), IEL
   43 NODE(1)=48*NHOLES+1
```

```
      NODE(2)=NODE(1)+NDW
      NODE(3)=NODE(2)+1
      NODE(4)=NODE(1)+1
      GO TO 47
   44 NODE(2)=NODE(1)
      NODE(3)=NODE(4)
      NODE(1)=NODE(2)+2*NDW
      NODE(4)=NODE(1)+1
      GO TO 47
   45 NODE(2)=NODE(1)+NDW-2
      NODE(3)=NODE(2)+1
      NODE(4)=NODE(3)+NDW
      NODE(1)=NODE(4)-1
      GO TO 47
   46 NODE(2)=NODE(1)
      NODE(3)=NODE(4)
      NODE(1)=NODE(2)+NDW
      NODE(4)=NODE(1)+1
   47 DO 48 I=1,4
      KDOF=2*NODE(I)
      ISS(IPNTR)=KDOF-1
      ISS(IPNTR+1)=KDOF
   48 IPNTR=IPNTR+2
   49 CONTINUE
C STORE DOF NUMBERS ORIGINALLY ASSIGNED TO INSIDE OF DAMAGED HOLE
      IDM=(IROW-1)*NHOLES+IDMGD
      IPNTR=ISS(IMASTR+IDM-1)+16
      NODER=IPNTR+47
      NODEL=NDT-47
      J=1
      DO 50 I=IPNTR,NODER
      CNSTRN (J)=ISS(I)
      ISS(I)=NODEL
      J=J+1
 50   NODEL=NODEL+1
C CONSTRAIN ALL VERTICAL DOFS ON BOTTOM EDGE
```

```
      NMBRCN=1                                                          DBL 0144
      DO 51 I=1,NDW                                                     DBL 0145
      ISS(NMBRCN)=CNSTRN (I*2)                                          DBL 0146
 51   NMBRCN=NMBRCN+1                                                   DBL 0147
C CONSTRAIN THE HORIZONTAL DOFS AT THE PAIR OF CENTER NODES ON BOTTOM EDDBL 0148
      ISS(NMBRCN)=CNSTRN(NELW)                                          DBL 0149
      NMBRCN=NMBRCN+1                                                   DBL 0150
      ISS(NMBRCN)=CNSTRN(NELW+2)                                        DBL 0151
      IPNTR=ISS(IMASTR+NH2+3)+8                                         DBL 0152
      ISS(IMASTR+NH2+4)=IPNTR                                           DBL 0153
C RE-ASSIGN DOF NUMBERS AROUND DAMAGED HOLE TO BOTTOM EDGE OF LUG SUBSTRDBL 0154
      NODEL=2*NDW                                                       DBL 0155
      DO 52 I=1,NODEL                                                   DBL 0156
      ISS(IPNTR)=CNSTRN (I)                                             DBL 0157
 52   IPNTR=IPNTR+1                                                     DBL 0158
C REPLACE THE DOF NUMBERS ORIGINALLY ASSIGNED TO THE DAMAGED HOLE WITH  DBL 0159
C THE HIGHEST DOF NUMBERS WHICH WILL REMAIN WHEN ALL OTHERS ARE CONDENSEDBL 0160
      NODEL=96*NHOLES+8*NDW+1                                           DBL 0161
      NODER=NODEL+2*NELW+1                                              DBL 0162
      DO 53 I=NODEL,NODER                                               DBL 0163
      ISS(IPNTR)=I                                                      DBL 0164
 53   IPNTR=IPNTR+1                                                     DBL 0165
      IF( KT1 .EQ. KW ) GO TO 70                                        DBL 0166
      IMASTR=IBEGIN(4)                                                  DBL 0167
      LMASTR=IMASTR+NET-1                                               DBL 0168
      WRITE(KW,6002) (ISS(I),I=IMASTR,LMASTR)                           DBL 0169
 6002 FORMAT(22H0MASTER ASSEMBLY LIST:,/,10H POINTERS:,20I5)            DBL 0170
      IMASTR=LMASTR+1                                                   DBL 0171
      LMASTR=IMASTR+63                                                  DBL 0172
      DO 60 N=1,NH2                                                     DBL 0173
      WRITE(KW,6003) N,(ISS(I),I=IMASTR,LMASTR)                         DBL 0174
 6003 FORMAT(17H0HOLE ELEMENT NO.,I3,10H  D.O.F.S:,/,15X,9HBOUNDARY:,16IDBL 0175
     @5,/,15X,15HHOLE INTERIOR: ,16I5,/,30X,16I5,/,30X,16I5)            DBL 0176
      IMASTR=LMASTR+1                                                   DBL 0177
 60   LMASTR=IMASTR+63                                                  DBL 0178
      LMASTR=IMASTR+31                                                  DBL 0179
```

```
      WRITE(KW,60030) (ISS(I),I=IMASTR,LMASTR)
60030 FORMAT(14H0QUAD4 S DOFS:,16I6,/,1H0,15X,16I6)
      IMASTR=LMASTR+1
      LMASTR=IEND(4)
      WRITE(KW,60031)
60031 FORMAT(21H0LUG ELEMENT D.O.F.S:)
      WRITE(KW,60032) (RSS(I),I=IMASTR,LMASTR)
60032 FORMAT(1H ,20I5)
 70   CALL ORK(NSIZE,RSS,ISS)
      CALL QUAD4(XY,THK,COORD,C,0,NODE,COORD,EF,ELK,BMAT,1,KW)
C ASSEMBLE FOUR QUAD4S
      N1=NH2+1
      N2=N1+3
      DO 72 N=N1,N2
   72 CALL ASMLTV(N,8,ELK,EF,RSS,ISS)
      NCON=KT1
      KT1=KW
      CALL HOLEL(COORD,THK,S,RI,RHOLE,IHOLE,B)
C ASSEMBLE UNDAMAGED HOLES
      DO 80 N=1,NH2
      IF( N .EQ. IDM) GO TO 80
      CALL ASMSUB(N,RHOLE,IHOLE,RSS,ISS)
 80   CONTINUE
C ASSEMBLE DAMAGED HOLE (WITHOUT RING)
 85   RO=RI*((1.0+PI/12.0)**4)
      CALL HOLEL(COORD,THK,S,RO,RHOLE,IHOLE,B)
      KT1=NCON
      CALL ASMSUB(IDM,RHOLE,IHOLE,RSS,ISS)
      DO 86 I=1,2
 86   ISAVE1(I)=ISZ(I)
      DO 87 I=1,6
      ISAVE2(I)=IBEGIN(I)
 87   ISAVE3(I)=IEND(I)
      CNODE=KT1
      KT1=KT2
      CALL LUG(WIDTH,LENGTH,NELW,THK,THK,C,NSZHL,RHOLE,IHOLE)
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```
      KT1=CNODE                                                          DBL 0216
      DO 88 I=1,2                                                        DBL 0217
 88   ISZ(I)=ISAVE1(I)                                                   DBL 0218
      DO 89 I=1,6                                                        DBL 0219
      IBEGIN(I)=ISAVE2(I)                                                DBL 0220
 89   IEND(I)=ISAVE3(I)                                                  DBL 0221
C ASSEMBLE LUG SUBSTRUCTURE                                              DBL 0222
      CALL ASMSUB(NH2+5,RHOLE,IHOLE,RSS,ISS)                             DBL 0223
      IMASTR=IBEGIN(5)-1                                                 DBL 0224
C CONSTRAIN NODES ORIGINALLY ASSIGNED TO HOLE CENTERS                    DBL 0225
      CNODE=100*NHOLES+2                                                 DBL 0226
      NCON=NMBRCN+1                                                      DBL 0227
      DO 92 NROW=1,2                                                     DBL 0228
      DO 90 N=1,NHOLES                                                   DBL 0229
      ISS(NCON)=CNODE                                                    DBL 0230
      ISS(NCON+1)=CNODE-1                                                DBL 0231
      NCON=NCON+2                                                        DBL 0232
   90 CNODE=CNODE-4                                                      DBL 0233
      CNODE=112*NHOLES+12                                                DBL 0234
   92 CONTINUE                                                           DBL 0235
C CONSTRAIN ALL DOFS WHICH WERE ORIGINALLY ASSIGNED TO DAMAGED HOLE AND DBL 0236
C WHICH WERE NOT USED ON BOTTOM EDGE                                     DBL 0237
      NODEL=2*NDW+1                                                      DBL 0238
      DO 105 I=NODEL,48                                                  DBL 0239
      ISS(NCON)=CNSTRN (I)                                               DBL 0240
 105  NCON=NCON+1                                                        DBL 0241
      NCON=NCON-1                                                        DBL 0242
      DO 106 I=1,NCON                                                    DBL 0243
 106  RSS(IMASTR+ISS(I))=0.0                                             DBL 0244
      DTHETA=PI/24.0                                                     DBL 0245
      DTHT=PI/12.0                                                       DBL 0246
      PO=2.0/(RI*THK*PI)                                                 DBL 0247
      THETA=0.0                                                          DBL 0248
      DO 120 I=1,7                                                       DBL 0249
      SS1=SIN(THETA-DTHETA)                                              DBL 0250
      SS2=SIN(THETA+DTHETA)                                              DBL 0251
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      IF( I .EQ. 1 ) SS1=0.0                                            DBL 0252
      IF( I .EQ. 13 ) SS2=0.0                                           DBL 0253
      PNODE=PO*THK*DTHETA*(SS2+SS1)                                     DBL 0254
      IF( KT1 .EQ. KW ) GO TO 110                                       DBL 0255
      WRITE(KW,6004) I,PNODE                                            DBL 0256
 6004 FORMAT(41H0CONSISTENT RR NODAL FORCE; GENERAL NODE ,I3,28H  SCALEDDBL 0257
     @ P (XBEARING FORCE)=,E12.5)                                       DBL 0258
 110  SCALE(2,I)=PNODE*SIN(THETA)                                       DBL 0259
      SCALE(1,I)=PNODE*COS(THETA)                                       DBL 0260
      IF (KT1 .EQ. KW ) GO TO 120                                       DBL 0261
      WRITE(KW,6005) I,(SCALE(J,I),J=1,2)                               DBL 0262
 6005 FORMAT(21H0SCALE FACTORS; NODE ,I3,9H X SCALE=,E12.5,11H   Y SCALEDBL 0263
     @=,E12.5)                                                          DBL 0264
 120  THETA=THETA+DTHT                                                  DBL 0265
      DO 125 I=8,13                                                     DBL 0266
      IMASTR=14-I                                                       DBL 0267
      DO 125 J=1,2                                                      DBL 0268
 125  SCALE(J,I)=SCALE(J,IMASTR)                                        DBL 0269
      DO 126 I=8,13                                                     DBL 0270
 126  SCALE(1,I)=-SCALE(1,I)                                            DBL 0271
      SCALE(1,7)=0.0                                                    DBL 0272
C COSINE LOADING IN ALL BUT DAMAGED HOLE IS SCALED UP BY BFORCE(I) FOR  DBL 0273
C HOLE NUMBER I                                                         DBL 0274
      NODEL=7                                                           DBL 0275
      IMASTR=IBEGIN(5)-1                                                DBL 0276
      DO 140 N=1,NH2                                                    DBL 0277
      IF( N .EQ. IDM ) GO TO 140                                        DBL 0278
      DO 130 I=1,13                                                     DBL 0279
      DO 130 J=1,2                                                      DBL 0280
      RSS(IMASTR+NODEL)=SCALE(J,I)*BFORCE(N)                            DBL 0281
 130  NODEL=NODEL+1                                                     DBL 0282
 140  NODEL=N*48+7                                                      DBL 0283
 145  CALL BCON(RSS,ISS)                                                DBL 0284
C CONDENSE OUT ALL DOFS EXCEPT THOSE IN DAMAGED HOLE                    DBL 0285
      I=1                                                               DBL 0286
      CALL STACON(I,NIDSS,RSS,ISS)                                      DBL 0287
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      DO 150 I=1,6                                                      DBL 0288
150   IBGSS(I)=IBEGIN(I)                                                DBL 0289
      NETSS=NET                                                         DBL 0290
      NDTSS=NDT                                                         DBL 0291
      NID=NIDSS                                                         DBL 0292
      IF (KT1 .EQ. KW) GO TO 160                                        DBL 0293
      WRITE(KW,6006)                                                    DBL 0294
6006 FORMAT(1H0,61X,8HEXIT DBL)                                         DBL 0295
160   RETURN                                                            DBL 0296
170   WRITE(KW,6007) RI,CLSPC                                           DBL 0297
6007 FORMAT(56H0*****PROGRAM INTERUPT INITIATED BY SUBROUTINE DBL *****DBL 0298
     @,//,27H USER SPECIFIED DIMENSIONS:,/,10X,13H HOLE RADIUS=,E12.5,/,DBL 0299
     @10X,30H CENTER LINE SPACING OF HOLES=,E12.5,//,87H SUCH DIMENSIONSDBL 0300
     @ WILL CAUSE UNACCEPTABLE PROBLEMS WITH HOLE ELEMENT AND MUST BE ALDBL 0301
     @TERED,//,21H RECOMMENDED CHANGES:,//)                             DBL 0302
      CLSPC=8.0*RI                                                      DBL 0303
      WRITE(KW,6008) WIDTH,CLSPC                                        DBL 0304
6008 FORMAT(33H LET RI BE LESS THAN OR EQUAL TO ,E12.5,56H OR LET CENTEDBL 0305
     @R LINE SPACING BE GREATER THAN OR EQUAL TO ,E12.5)                DBL 0306
      GO TO 190                                                         DBL 0307
180   WRITE(KW,6007) RI,CLSPC                                           DBL 0308
      CLSPC=12.0*RI                                                     DBL 0309
      WRITE(KW,6009) WIDTH,CLSPC                                        DBL 0310
6009 FORMAT(36H LET RI BE GREATER THAN OR EQUAL TO ,E12.5,53H OR LET CEDBL 0311
     @NTER LINE SPACING BE LESS THAN OR EQUAL TO ,E12.5)                DBL 0312
190   WRITE(KW,6010)                                                    DBL 0313
6010 FORMAT(51H0***** EXECUTION TERMINATED IN SUBROUTINE DBL *****)     DBL 0314
      STOP                                                              DBL 0315
      END                                                               DBL 0316
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